BIOLOGICAL ASSESSMENT

Effects of the Central Valley Project and State Water Project on Delta Smelt

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Contents

Figures

C-045313

Tables

Chapter 1
INTRODUCTION

As part of the formal consultation process between the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation in regard to delta smelt, this biological assessment enumerates potential effects on delta smelt of existing water transport and diversion facilities, specifically the Central Valley Project of the Bureau of Reclamation and the State Water Project of the California Department of Water Resources. Other facilities and factors impacting delta smelt are also described in this assessment.

Although they may be the most studied of factors impacting delta smelt, the Central Valley Project and State Water Project have not been shown to be the factor of greatest importance. Analyses have not been done to evaluate and compare relative magnitude of impacts associated with biological and hydrological conditions and basinwide water development and use. This assessment and consultation process is intended only to evaluate the potential impact on delta smelt of those operations over which the federal and state water projects have direct control and responsibility. The many other factors identified in this report and in other studies need to be evaluated further.

Delta smelt is listed as a threatened species under the Endangered Species Act of 1973. Section 7 of the Endangered Species Act requires federal agencies to consult on any actions they take that may affect species listed as threatened or endangered. Operations of the Central Valley Project and State Water Project clearly have the potential to affect delta smelt; therefore, the U.S. Bureau of Reclamation and the U.S. Fish and Wildlife Service will initiate a Section 7 consultation. The consultation will be based on the present CVP/SWP operations as modified by requirements of the Section 7 consultation on winter-run Chinook salmon. This assessment has not included operations required by the Central Valley Project Improvement Act, because such operations have not been defined with enough certainty to be included.

Although the primary purpose of this biological assessment is to fulfill requirements of the federal Endangered Species Act, it is also intended for use in any consultation relative to delta smelt that may be undertaken pursuant to the California Endangered Species Act.

The delta smelt occurs primarily in the lower Sacramento and San Joaquin rivers, in the delta above their confluence, and in Suisun Bay. During wet years, it is also found in San Pablo Bay. The Bay/Delta estuary extends from the Golden Gate, at the entrance to San Francisco Bay, upstream in the Sacramento and San Joaquin rivers to the uppermost influence of the tides (Figure 1). The Sacramento and San Joaquin rivers are the major streams in California's Central Valley, and this vast estuary is one of the most highly modified estuaries in the world (Conomos 1979).

This assessment describes the biology of delta smelt, CVP/SWP facilities and how they are operated, potential factors affecting delta smelt abundance and distribution, and the overall effect of coordinated CVP/SWP operations on delta smelt. Again, since definitive knowledge of factors affecting delta smelt is limited, data and current hypotheses examined for this report are expected to undergo further assessment and revision during the consultation process, as necessary and appropriate. Further analyses are underway, and results will be documented for use in the Section 7 consultation.

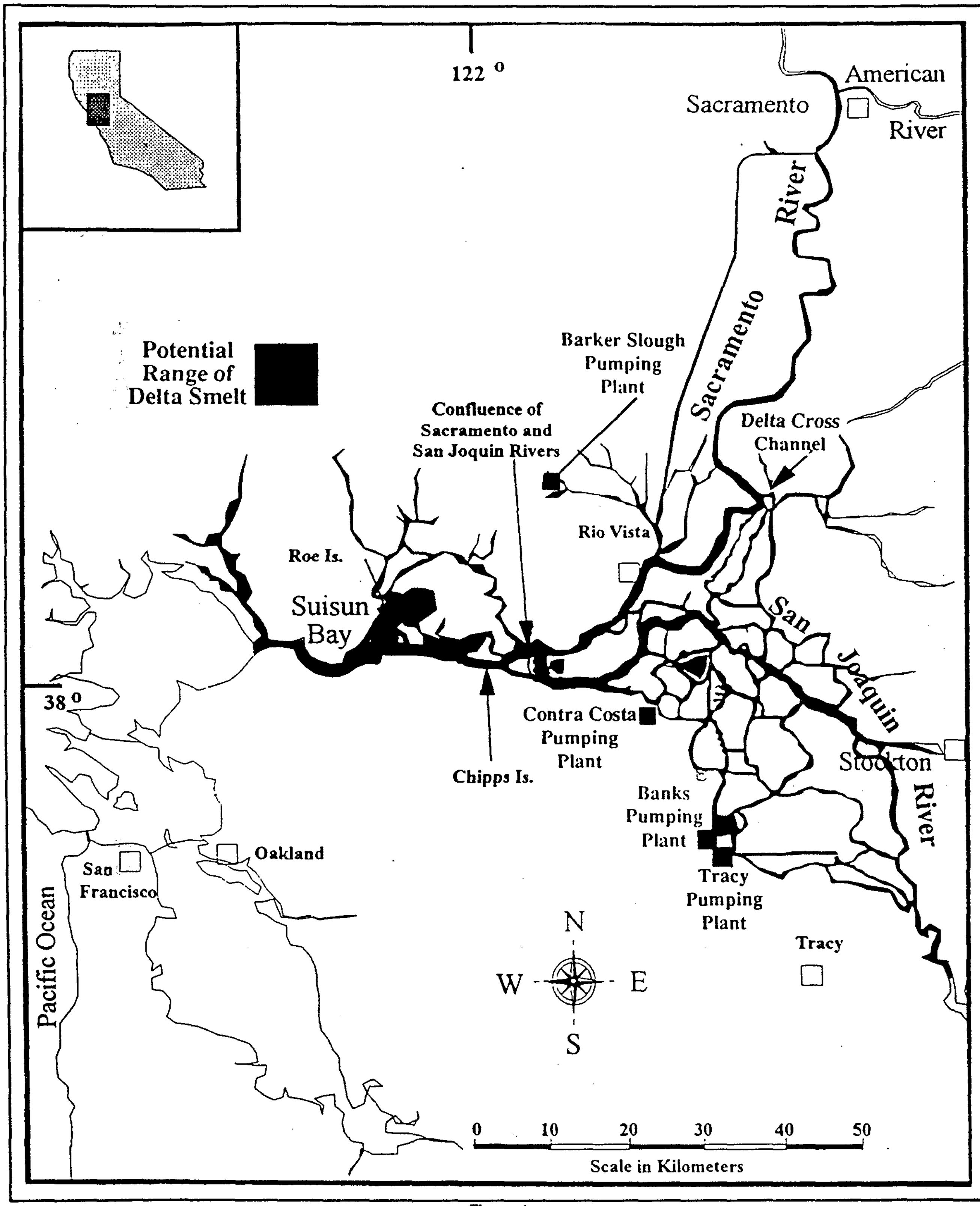

Figure 1
SACRAMENTO-SAN JOAQUIN ESTUARY
Adapted from Sweetnam and Stevens 1993.

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Chapter 2

BASIC BIOLOGY AND LIFE HISTORY

Taxonomy

Delta smelt have been described by Moyle *et al* (1989) as follows:

> Delta smelt (*Hypomesus transpacificus*) are slender-bodied fish that typically reach 60-70 mm standard length (SL), although a few may reach 120 mm SL. The mouth is small, with a maxilla that does not extend past the mid-point of the eye. The eyes are relatively large, with the orbit width contained approximately 3.5-4 times in head length. Small, pointed teeth are present on the upper and lower jaws. The first gill arch has 27-33 gill rakers and there are 7 branchiostegal rays. The pectoral fins reach less than two-thirds of the way to the bases of the pelvic fins. There are 9-10 dorsal fin rays, 8 pelvic fin rays, 10-12 pectoral fin rays, and 15-17 anal fin rays. The lateral line is incomplete and has 53-60 scales along it. There are 4-5 pyloric caeca.
>
> Live fish are nearly translucent and have a steely-blue sheen to their sides. Occasionally there may be one chromatophore between the mandibles, but usually there is none.

Like other members of the Osmeridae family, delta smelt possess an adipose fin and have a distinct odor of cucumbers when fresh (Moyle 1976, Wang 1986).

Until 1961, the delta smelt was considered to be the same species as the widely distributed pond smelt (*Hypomesus olidus*). Under this assumption, pond smelt were introduced in 1959 from Japan into several California lakes and reservoirs as a forage fish for trout (Wales 1962). Delta smelt and pond smelt were first recognized as distinct species by Hamada (1961, cited by Moyle *et al* 1989). The delta smelt retained *H. olidus*, while the pond smelt was renamed *H. sakhalinus*. A few years later, McAllister (1963) determined that *H. olidus* was not present in California waters and named *H. transpacificus*, which he described as having California (*H. t. transpacificus*) and Japanese (*H. t. nipponensis*) subspecies. Further studies have shown these two subspecies should be recognized as distinct species: *H. transpacificus*, (delta smelt) and *H. nipponensis* (wakasagi) (Moyle 1980). Results from recent electrophoretic studies indicate that delta smelt and wakasagi are distinct species (Stanley *et al* 1993).

Life Cycle

The delta smelt is a euryhaline species found only in the Sacramento-San Joaquin Estuary. Much of the information available on the life history of delta smelt has been derived from the sampling programs described in Chapter 3. Delta smelt commonly occur, presumably in schools, in the surface and shoal waters of the lower reaches of the Sacramento River below Isleton, the San Joaquin River below Mossdale, through the Delta, and into Suisun Bay (Moyle 1976, Moyle *et al* 1992) (refer to Figure 1). Delta smelt have been found as far upstream on the Sacramento River as the mouth of the American River (Stevens *et al* 1990). In high flow years, delta smelt may also be washed temporarily into San Pablo Bay, as in the winter of 1992-93 (D. Sweetnam, pers comm, cited by Moyle *et al* 1993). When not spawning, they tend to concentrate just upstream of the entrapment zone (described in Chapter 5; Moyle *et al* 1989). When the entrapment zone is in Suisun Bay and both deep and shallow water exists, delta smelt are caught most frequently in shallow water (Moyle *et al* 1992). More information on the geographic distribution of delta smelt under high and low outflow conditions can be found in Chapter 5.

Adults migrate in winter and spring from brackish water to fresh water, where they spawn from about February through June (Wang 1986). Ripe female smelt have been collected as early as December and into April, but are most abundant in February and March (Moyle 1976). Data for 1989 and 1990 indicate spawning occurred from mid-February to late June or July, with peaks in April and early May (Wang 1991). Past research indicates an almost complete spawning failure is possible in some years (Erkkila *et al* 1950, cited by Sweetnam and Stevens 1991).

Wang (1991) suggests the long spawning season (at least 4 or 5 months) indicates delta smelt may spawn more than once during the spawning season, or individuals may mature at different times and spawn only once. Based on findings by Moyle *et al* (1992), the latter may be more likely. Eggs removed from females collected in mid-January and early March 1973 were about the same size in each ovary, indicating each fish probably spawned over a relatively short period. If delta smelt were multiple spawners, eggs would be at various stages of development and size. Also, since collections were made a month and a half apart, individuals may mature at different times during the spawning season. Recent histological analyses further support this spawning theory, because all the eggs develop synchronously (S. Doroshov, pers comm, cited by Sweetnam and Stevens 1993).

Recent culturing efforts by BioSystems Analysis, Inc., and University of California, Davis, indicate spawning success in the laboratory appears to vary depending on whether fish are captured early or late in the season. Gonadal development occurs from October to April, especially in March and April. Development is asymmetric, with the left gonad being considerably larger (Mager 1993). A ripe gonad may have 1,000-1,400 eggs. However, fertility and percent hatch ranged from zero to 80 percent and was poorer in late spring. In collections of adult fish, females were more common than males later in the spawning season (mid-April) (88.5% females, n=140) (Lindberg 1992).

Moyle *et al* (1992) found no correlation between female length and fecundity. Females of 59-70 mm SL ranged in fecundity from 1,247 to 2,590 eggs per fish, with an average of 1,907. Delta smelt fecundity is relatively low in comparison to longfin smelt (*Spirinchus thaleichthys*), the other euryhaline smelt present in the Delta, which has fecundity of 5,000 to 25,000 eggs per female (Moyle 1976).

Spawning has been reported to occur at about 45 to 59 degrees F (7-15°C) in tidally-influenced rivers and sloughs, including dead-end sloughs and shallow edge-waters of the upper Delta and Sacramento River above Rio Vista (Radtke 1968, Wang 1986). Evidence of some spawning has also been recorded in Montezuma Slough and, more recently, in Suisun Slough (P. Moyle, unpubl data). However, typical April-June water temperatures in the Delta are 59 to 70 degrees F (15-23°C), which are higher than the reported spawning range. Post-hatch larvae of 5.0 mm total length (TL) were collected in 1991 at 73 degree F water (22.8°C), while water temperatures for the previous 7 to 14 days at the same location were 69.5 to 70 degrees F (20.8-21.7°C). However, the larvae may have been spawned and carried in from an area of cooler temperatures (Sweetnam and Stevens 1991).

Most spawning occurs in fresh water, but some may occur in brackish water in or near the entrapment zone (Wang 1991). The demersal, adhesive eggs sink and attach to hard substrates, such as submerged tree branches and roots, gravel or rocks, and submerged vegetation (Moyle 1976, Wang 1986).

Laboratory observations indicate that delta smelt are broadcast spawners that spawn in a current, usually at night, distributing their eggs over a local area (Lindberg 1992, Mager 1993). The eggs (1.0 mm) form an adhesive foot that appears to stick to most surfaces. Eggs attach singly to the substrate, and few eggs were found on vertical plants or sides of the culture tank (Lindberg 1993). Mager (1993) found that larvae hatched in 10-14 days under laboratory conditions, with absorption of the yolk-sac in 150 hours and of the oil droplet in 200 hours. Larvae began feeding on phytoplankton on day 4, rotifers on day 6, and Artemia nauplii at day 14. They did best on a rotifer diet until day 10-15 but were not selective when fed a mixed diet. Little digestion was observed until day 8. Lindberg (1992) found that hatch occurred at 9 days, yolk absorption at 4 days post hatch, exogenous feeding at 4-5 days post hatch, and oil globule absorption at 10 days post hatch (at 17 degrees C).

Newly hatched larvae are planktonic and drift downstream near the surface in inshore and channel areas to the upper end of the entrapment zone (Wang 1986, Moyle *et al* 1992). In the laboratory, yolk-sac fry were found to be positively phototaxic, swimming to the lightest corner of the incubator, and negatively buoyant, actively swimming to the surface. The behavior of post-yolk-sac fry was more variable; they were more evenly distributed throughout the water column (Lindberg 1992).

Juvenile and adult delta smelt commonly occur in the surface and shoal waters of the lower reaches of the Sacramento River below Isleton, the San Joaquin River below Mossdale, through the Delta, and into Suisun Bay (Moyle 1976, Moyle *et al* 1992). Growth is rapid through summer, with juveniles reaching 40 to 50 mm FL[1] by early August (Radtke 1966). Growth slows in the fall and winter, presumably to allow for gonadal development. Adult smelt reach 55 to 70 mm SL in seven to nine months, and those that survive spawning may grow as large as 120 mm SL (Moyle 1976). Most delta smelt do not grow larger than 80 mm FL (Moyle *et al* 1992). The largest recorded smelt was 126 mm FL (Stevens *et al* 1990).

Length/frequency distribution of the short lifespan of delta smelt indicates most fish live only one year and die after spawning (Stevens *et al* 1990, Moyle *et al* 1992); however, some do apparently survive for two years (Moyle 1976). Recent culturing work indicates that after spawning, males die off more rapidly in May and June (Mager 1993). Smelt larger than 50 mm FL become increasingly rare in March through June samples (Moyle *et al* 1992), and by late summer, the young of the year dominate trawl catches (Moyle *et al* 1989). There is generally an abrupt change from a single-age adult cohort during spring spawning to a dominance of juveniles in the summer (Radtke 1966).

1 FL = Fork Length; SL = Standard Length; TL = Total Length.

HISTORICAL ABUNDANCE AND DISTRIBUTION

Several surveys have collected data on delta smelt as part of larger sampling programs. Some surveys focused on specific species such as striped bass or salmon; others were designed to monitor fish populations in specific areas. During the past few years, sampling programs have been modified and expanded substantially to provide more information on delta smelt.

Information on delta smelt is included in databases from the summer tow-net survey, fall midwater trawl survey, Delta Outflow/San Francisco Bay Study, Chipps Island trawl survey, beach seine survey, Suisun Marsh survey, and fish salvage operations at the SWP and CVP. Although these programs were not designed to measure delta smelt distribution and abundance, the databases provide the best information available on delta smelt abundance, distribution, and trends. Each sampling program has relative strengths and weaknesses, associated with such factors as gear types (biases, net efficiencies), channel area sampled, seasonal timing of survey, and geographic area covered. Although the size of the delta smelt population cannot be accurately estimated from the available data, the data do provide indices of general population trends. Figure 2 shows trends in delta smelt populations as indexed by the seven databases. This chapter briefly describes each of the databases and the observed trends.

Summer Tow-Net Survey

The Department of Fish and Game has conducted the tow-net survey each summer since 1959 (except 1967 and 1968), primarily to provide an abundance index for young striped bass. About 30 sites in San Pablo Bay and the Delta (Figure 3) are now surveyed for five days at 2-week intervals from June until the average size of young bass is 38 mm, in July or August.

Although the tow-net survey was primarily designed to sample striped bass abundance, data have also been collected on other species, including delta smelt. Two to five sampling runs have been completed each survey year; for consistency, the database includes only the first two sampling runs of each year. Abundance indices for each sampling run are calculated as the product of the total catch at each site and the estimated water volume (in acre-feet) for the site divided by 1000, a convenient scaling factor. A mean site index for the two sampling runs is calculated, with the annual Delta/Estuary index representing the sum of all sites (Stevens *et al* 1990).

The tow-net index is considered one of the best measures of delta smelt abundance, because it covers much of the species' habitat and represents the longest historical record. However, the index may underestimate abundance in high flow years, when many fish are carried to San Pablo Bay (Moyle *et al* 1992). Also, some potentially important habitat such as Cache Slough is not sampled. To maintain survey continuity with respect to the tides, additional stations were not added for areas such as Cache Slough. A larval purse seine has been added to the study to sample this area, but results are not yet available. Another concern is that the timing of delta smelt spawning varies (Wang 1991), so the size and associated catchability of young fish by the onset of tow-net sampling may change from year to year. Increased mortality of early-spawned delta smelt could

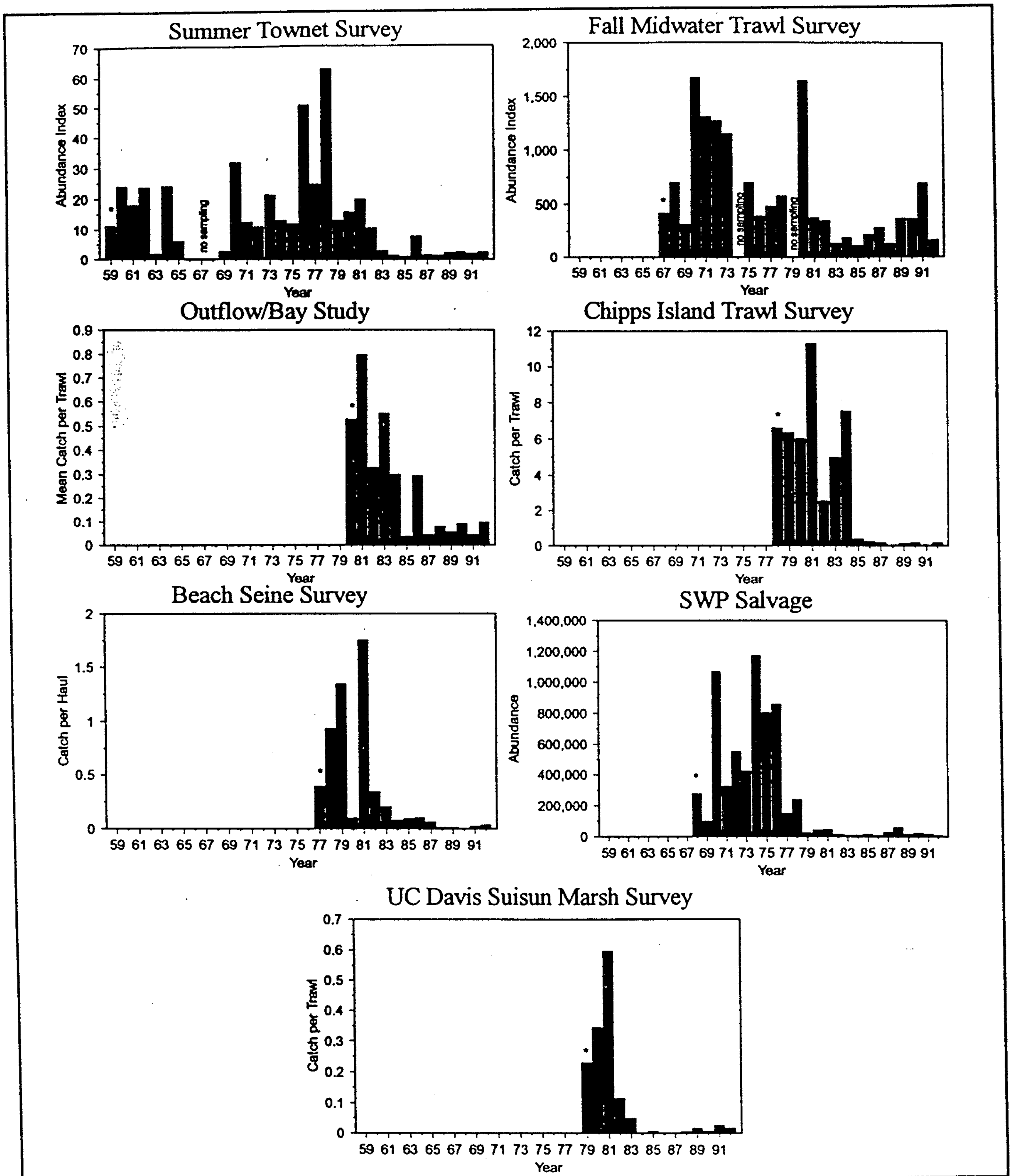

Figure 2

TRENDS IN DELTA SMELT POPULATIONS, AS INDEXED BY SEVEN INDEPENDENT SURVEYS

Note that not all surveys were conducted in all years shown.

Source: Sweetnam and Stevens 1993, updated from Stevens *et al* 1990.

also result in an underestimate of year-class strength (Dale Sweetnam, pers comm).

Results of the summer tow-net surveys are summarized in Figures 4 and 5. Abundance indices vary considerably but values have generally remained low from the 1980s until 1993 (Figure 4). The 1993 index is the highest since 1982, and delta smelt appear to be much more widely distributed than in recent years. The reduced population levels during the 1980s appears to have been consistent throughout the Delta and Suisun Bay (Figure 5), but declines may have occurred as early as the mid-1970s in the eastern and southern portions of the Delta.

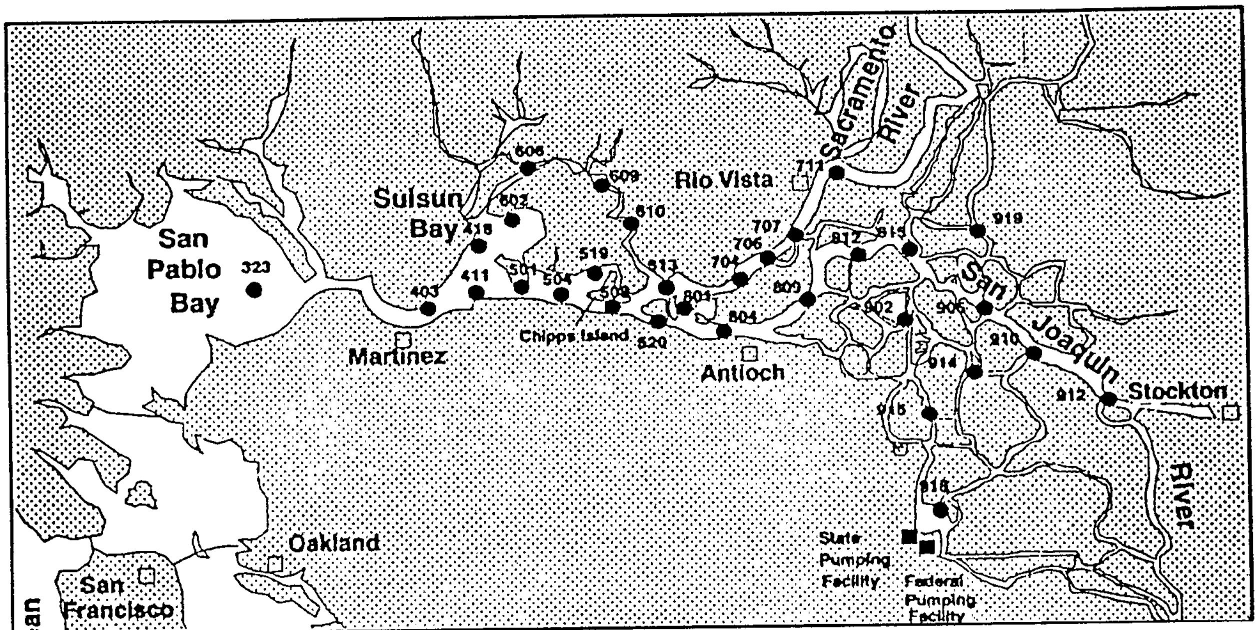

Figure 3
SUMMER TOW-NET SURVEY SAMPLING SITES IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

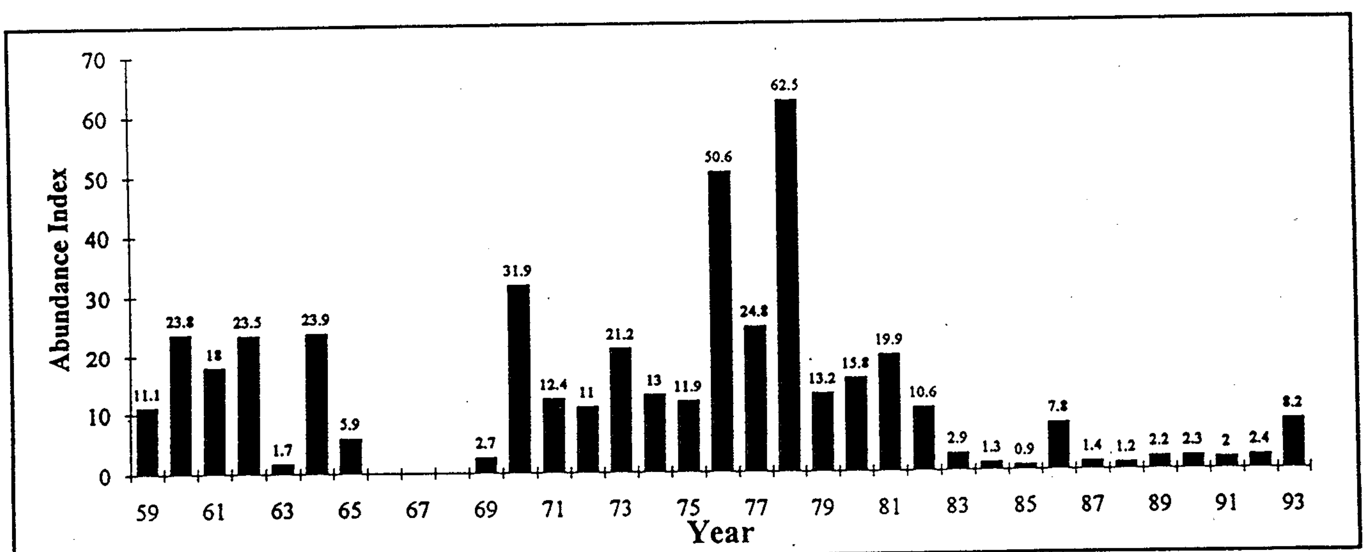

Figure 4
DELTA SMELT SUMMER TOW-NET INDEX, 1959-1993
No Sampling in 1966 to 1968.

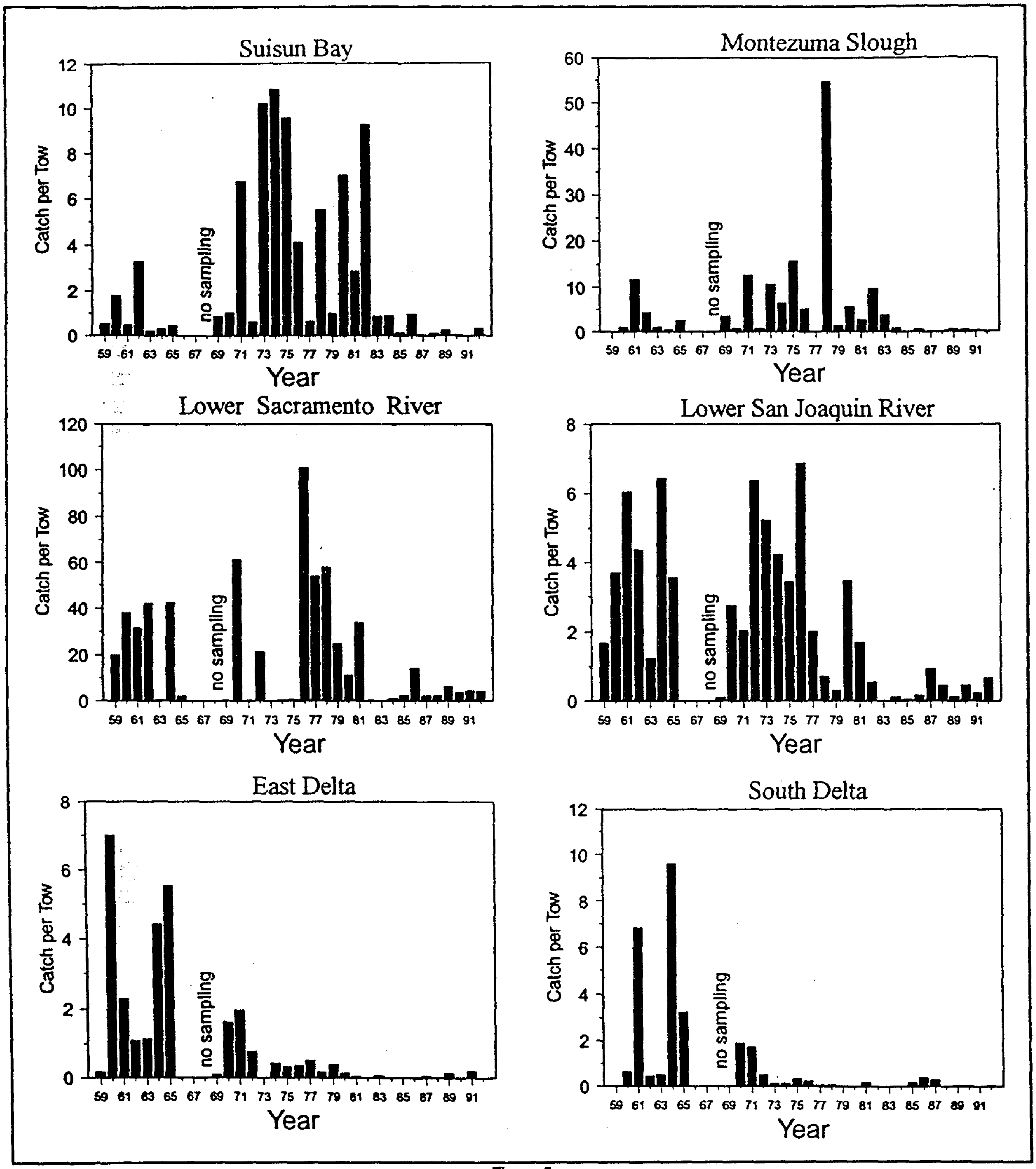

Figure 5

MEAN CATCH PER TOW OF DELTA SMELT, BY AREA, FROM THE SUMMER TOW-NET SURVEY

Note differences in the scale used for each area. Source: Sweetnam and Stevens 1993.

Fall Midwater Trawl Survey

Since 1967, the Department of Fish and Game has conducted a fall midwater trawl survey to determine abundance of striped bass and other species. The survey area includes about 87 sites from the Delta to San Pablo Bay (Figure 6). Additional stations have recently been added to improve coverage for delta smelt, but they are not used to develop the index for delta smelt (Sweetnam 1992). Until 1980, the survey lasted from late summer through the following March but now is from September through December. No sampling was conducted in 1974 and 1979, nor in November 1969 and September and December 1976. Additional months were included in 1991, 1992 (January to March), and 1993 (January to August) to increase sampling for delta smelt.

Monthly delta smelt indices are calculated for 17 subareas of the estuary as the product of the mean catch from each subarea and a weighting factor that is proportional to the estimated volume in each subarea. An annual index is calculated as the sum of monthly indices from each subarea from September through December. Missing data for 1969 and 1976 were estimated from interpolation or extrapolation (Stevens *et al* 1990).

Abundance indices have also been developed using the surface area of each site rather than the volume. The rationale was that delta smelt frequently school near the water surface, so dividing by the total volume may not be an accurate indication of abundance, particularly when sampling in narrow channels. However, indices based on volume were similar to those

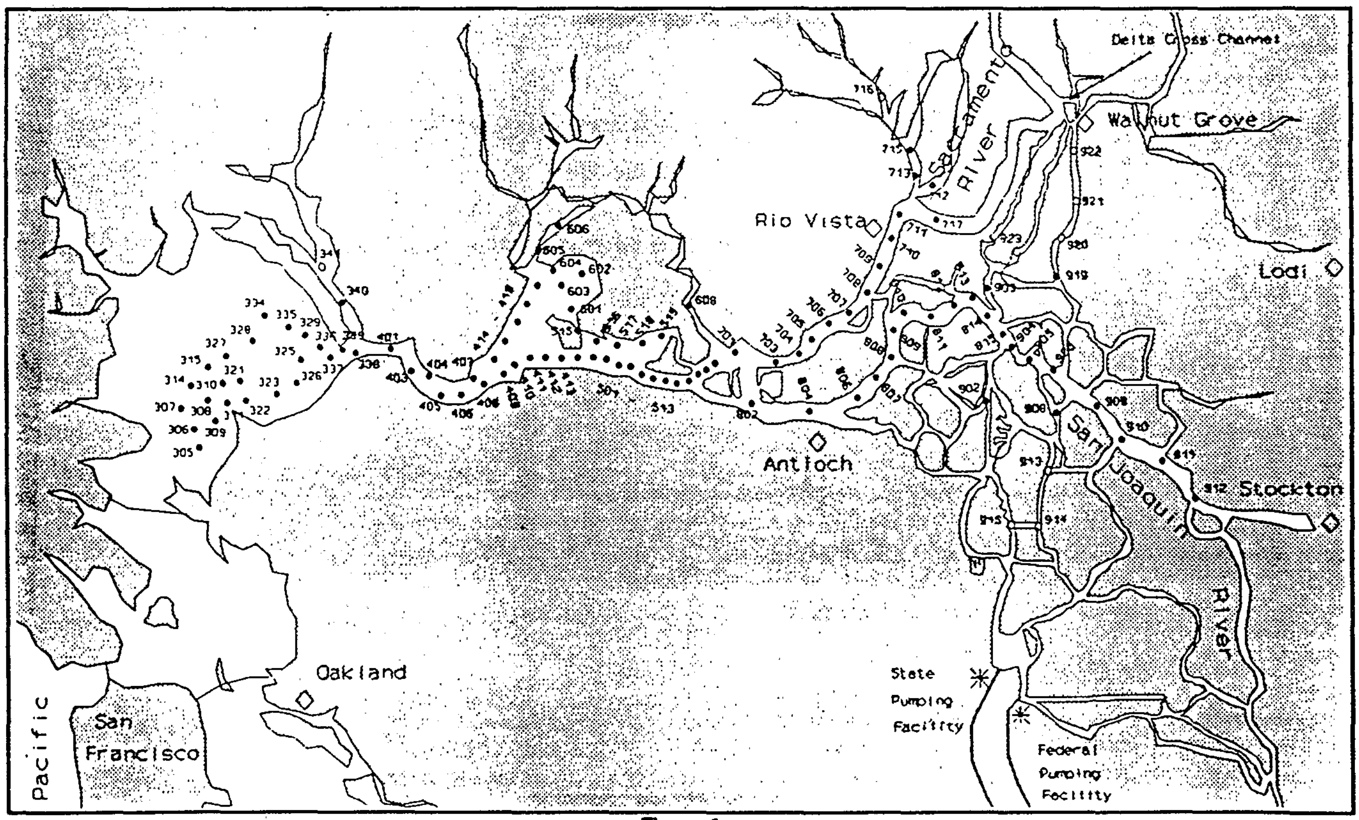

Figure 6
FALL MIDWATER TRAWL SAMPLING SITES IN THE SACRAMENTO-SAN JOAQUIN ESTUARY
● Original striped bass stations. ○ Added delta smelt stations.

developed by surface area, so the index remains based on volume (Dale Sweetnam, DFG, pers comm).

The midwater trawl provides a good index of smelt abundance because it covers most of the range of delta smelt. However, the index is questionable as an actual measure of total population size. Samples are collected principally from higher-velocity, midchannel areas and only during daytime, causing unquantified levels of gear selectivity and sampling bias. As evidence, efficiency of the midwater trawl in catching delta smelt appears to change over the course of the year. Sweetnam and Stevens (1993) reported that the midwater trawl was about 2.6 times more effective at sampling striped bass than delta smelt in August 1991 and 1.8 times more effective in January 1992. Hence, population size estimates by Stevens *et al* (1990) based on the ratio of delta smelt to striped bass in the fall midwater trawl are not considered accurate. Although the midwater trawl data do not produce satisfactory estimates of stock size, calculated indices remain reasonable evidence of abundance trends (Sweetnam and Stevens 1993).

Results of the midwater trawl surveys are presented in Figure 2. While indices have been highly variable, abundance has usually been low since 1981, except in 1991, when the index was the eighth highest on record. Indices were also low in 1967, 1969, 1976, and 1977, but they rebounded more quickly than in the 1980s. Initial results from the 1993 survey indicate that the September index alone is 375, higher than the annual index for all years in the past decade except 1991.

The midwater trawl also indicates changes in population distribution. Figure 7 presents distribution trends for the eastern Delta, lower San Joaquin River, lower Sacramento River, Montezuma Slough/Grizzly Bay, eastern Suisun Bay, and western Suisun Bay. In drought years such as 1976-1977 and 1987-1992, the population was concentrated in upstream channels in the lower Sacramento River. In wetter years, the population was more broadly distributed, extending into Montezuma Slough/Grizzly Bay, eastern Suisun Bay, and occasionally western Suisun Bay. Initial survey results from September 1993 are consistent with this pattern.

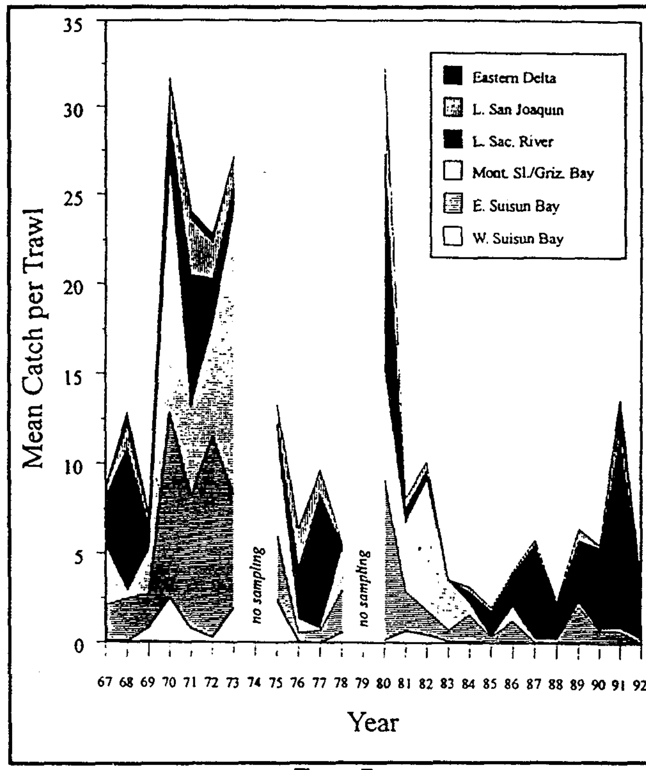

Figure 7
MEAN CATCH PER TRAWL FROM THE FALL MIDWATER TRAWL SURVEY FOR SPECIFIC AREAS OF THE SACRAMENTO-SAN JOAQUIN ESTUARY
Source: Sweetnam and Stevens 1993.

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Delta Outflow/ San Francisco Bay Study

Since 1980, the Delta Outflow/San Francisco Bay Study of the Interagency Ecological Studies Program[1] has sampled 42 locations from South San Francisco Bay to the western Delta. Catch per unit effort is calculated based on monthly 12-minute net tows. The survey is conducted year-round and reveals gross trends in fish and invertebrate abundance. This study collects both juvenile and adult delta smelt.

A major drawback of delta smelt data collected in the outflow/bay study is that the area east of Antioch is not sampled, so an important part of the species' range is excluded. Hence, while Figure 2 shows a dramatic decline in delta smelt during the 1980s, the trend may be largely a result of an upstream shift in distribution during the drought.

Chipps Island Trawl Survey

The Interagency Program's annual midwater trawl surveys at Chipps Island, in upper Suisun Bay, are primarily to capture released coded-wire-tagged salmon, but they also measure abundance of outmigrating Chinook salmon. The survey has been conducted April through June since 1976. Numbers of delta smelt captured incidentally in the trawl are recorded, allowing an index to be calculated based on catch per trawl. The major deficiency with this index is that only one location is sampled, so the index is strongly affected by changes in delta smelt distribution. Hence, the significantly lower catch-per-trawl levels after 1986 (Figure 2) could be partly a result of a distribution shift during the drought. An additional concern is that data are from relatively high-velocity, midchannel areas, where delta smelt may not necessarily be abundant during April though June.

Beach Seine Survey

The Interagency Program has conducted a beach seine survey at 23 sites from the Delta and Sacramento River upstream to the mouth of the American River. Since 1977, surveys have been performed several times each month from January to April, May, or June. This survey samples low-velocity water near the shoreline rather than high-velocity, midchannel areas. This survey reflects the numbers of adult smelt, which select shallow water as they move upstream to spawn. However, 20- to 30-mm juvenile smelt have also been taken. Results are consistent with general declines in the 1980s shown for other indices (Figure 2).

Suisun Marsh Survey

Under contract to the Department of Water Resources, students and staff at the University of California, Davis, have sampled the interior channels of Suisun Marsh since 1979. Otter trawl samples are taken monthly at a number of sites, including two in Montezuma Slough. An abundance index is calculated for delta smelt based on catch per tow (Figure 2). This sampling program also may not represent trends in overall Delta abundance. Although the decline in catch per tow in the 1980s is consistent with other surveys, the trend may be partly due to an upstream shift in distribution during the recent drought.

1 The Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary was formed in 1970. In 1993, member agencies are the California Department of Water Resources, U.S. Bureau of Reclamation, California Department of Fish and Game, U.S. Fish and Wildlife Service, U.S. Geological Survey, State Water Resources Control Board, U.S. Army Corps of Engineers, and U.S. Environmental Protection Agency.

SWP and CVP Fish Salvage Operations

Fish salvage data from the SWP and CVP facilities provide a useful, long-term record for delta smelt juveniles and adults) However, utility of the database is limited because of inconsistencies in the taxonomic identification and enumeration of delta smelt. Salvage data before 1979 are particularly suspect because of identification and other data quality problems. Also, the fish screens are relatively inefficient for fish less than 25 millimeters. The databases are also probably poor indicators of population abundance because annual salvage varies depending on seasonal and annual shifts in geographic distribution. Annual variations in water export rates also affect the numbers of fish diverted and efficiencies of the fish screens. Salvage values represent estimated delta smelt collected at the fish screens, not losses of sn to the water diversions. Nonetheless, salvag may provide an index of the timing and ma tude of losses.

At the CVP, the annual salvage estimate about 45,000 delta smelt in 1979 and 1980, w smelt species identification began (Stevens *et* 1990) (Figure 8). Salvage increased to ab 275,000 delta smelt in 1981, and has been low since 1982, ranging from 2,000 to 34,000 fis

At the SWP, less than 300,000 delta smelt w salvaged in 1968 and in 1969, the initial years sampling (Stevens *et al* 1990). From 1970 to 1 salvage ranged from about 300,000 to m than 1 million delta smelt. Results from su sequent years are shown in Figure 8. Delta s salvage declined dramatically in 1977 (146, and 1978 (238,000). Relatively few delta sme have been salvaged since 1979.

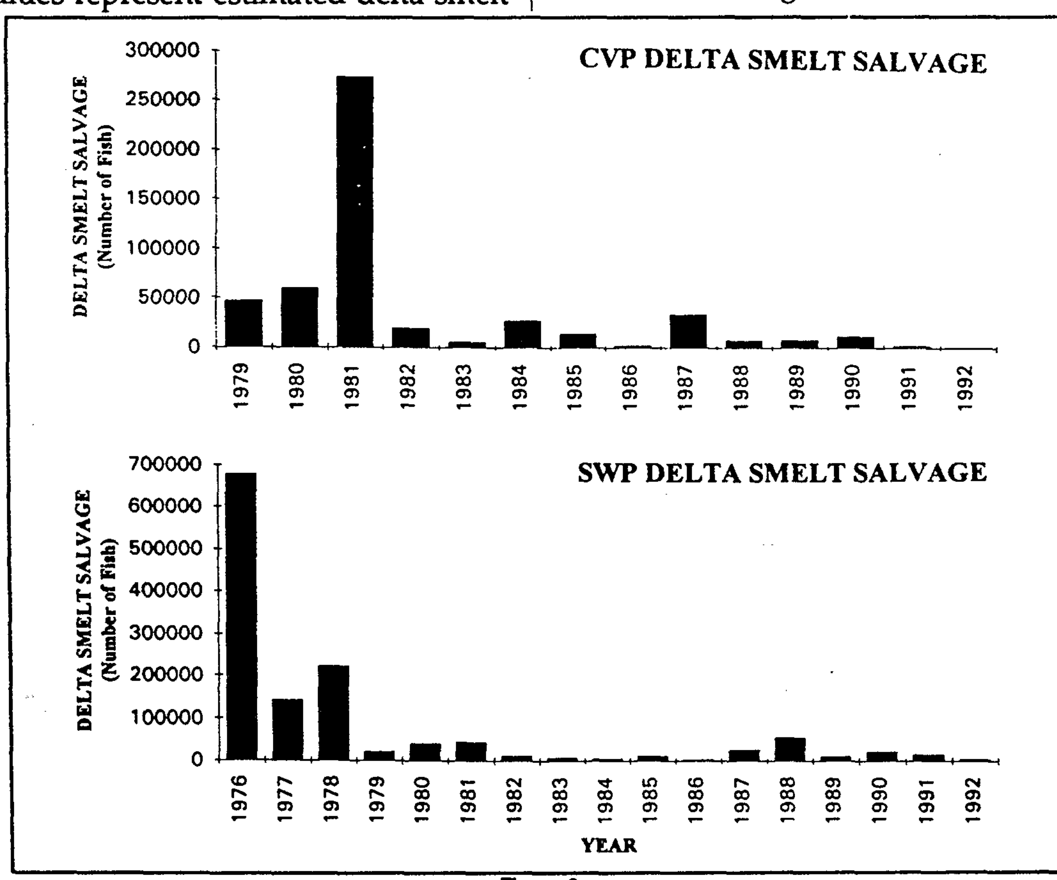

Figure 8

ANNUAL SALVAGE ESTIMATES FOR DELTA SMELT AT THE CVP AND SWP FISH FACILITIES

Data before 1979 are not included because of identification problems described in the text.

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CENTRAL VALLEY PROJECT AND STATE WATER PROJECT DELTA FACILITIES AND OPERATIONS

Two major interbasin water delivery systems — the State Water Project and the federal Central Valley Project — divert water from the southern Delta. Both projects include major reservoirs north of the Delta, and both transport water released from storage to areas south and west of the Delta (Figure 9).

The main purpose of the State Water Project is to store water and distribute it to areas of need in Northern California, the San Francisco Bay Area, the San Joaquin Valley, and Southern California. Other project functions include flood control, water quality, power generation, recreation, and fish and wildlife enhancement. The SWP includes 14 reservoirs; the North Bay and South Bay aqueducts; the California Aqueduct including the East, West, and Coastal branches; and power and pumping plants. The California Aqueduct extends more than 600 miles — two-thirds the length of California. It is the largest state-built, multi-purpose water project in the country.

The primary purpose of the federal Central Valley Project is to provide water for irrigation throughout California's great Central Valley. Other functions include urban water supply, water quality, flood control, power generation, recreation, and fish and wildlife habitat enhancement. The CVP includes 20 reservoirs; 500 miles of canals, including the Delta-Mendota canal; and other facilities.

Some facilities have been developed for joint use by the CVP and SWP. These include San Luis Reservoir, O'Neill Forebay, more than 100 miles of the California Aqueduct, and related pumping facilities.

Use of Delta channels for conveying water supply began in 1940, with completion of the Contra Costa Canal — the first unit of the Central Valley Project. Since initial operation of Shasta Dam in 1944 and the Delta-Mendota Canal and Delta Cross Channel in 1951 (all CVP) and Oroville Reservoir and the California Aqueduct in 1968 (both SWP), water project diversions from the Delta have increased steadily, to about 6 million acre-feet annually.

State Water Project Facilities, Capacity, and Demand

Banks Pumping Plant, about 12 miles northwest of Tracy, provides the initial lift of water from sea level to an elevation of 244 feet at the beginning of the California Aqueduct. Water entering the aqueduct flows to Bethany Reservoir, from which South Bay Aqueduct diverts water. Most of the water continues south, by gravity, to O'Neill Forebay, where it is pumped into San Luis Reservoir or conveyed to the San Joaquin Valley and Southern California.

An open intake channel conveys water to the Harvey O. Banks Delta Pumping Plant from Clifton Court Forebay. The forebay provides storage for off-peak pumping and permits regulation of flows into the pumping plant.

All water arriving at Banks Pumping Plant first flows through the primary intake channel of the John E. Skinner Delta Fish Protective Facility. Fish screens directly across the intake channel direct fish into bypass openings leading into the fish salvage facilities. The main

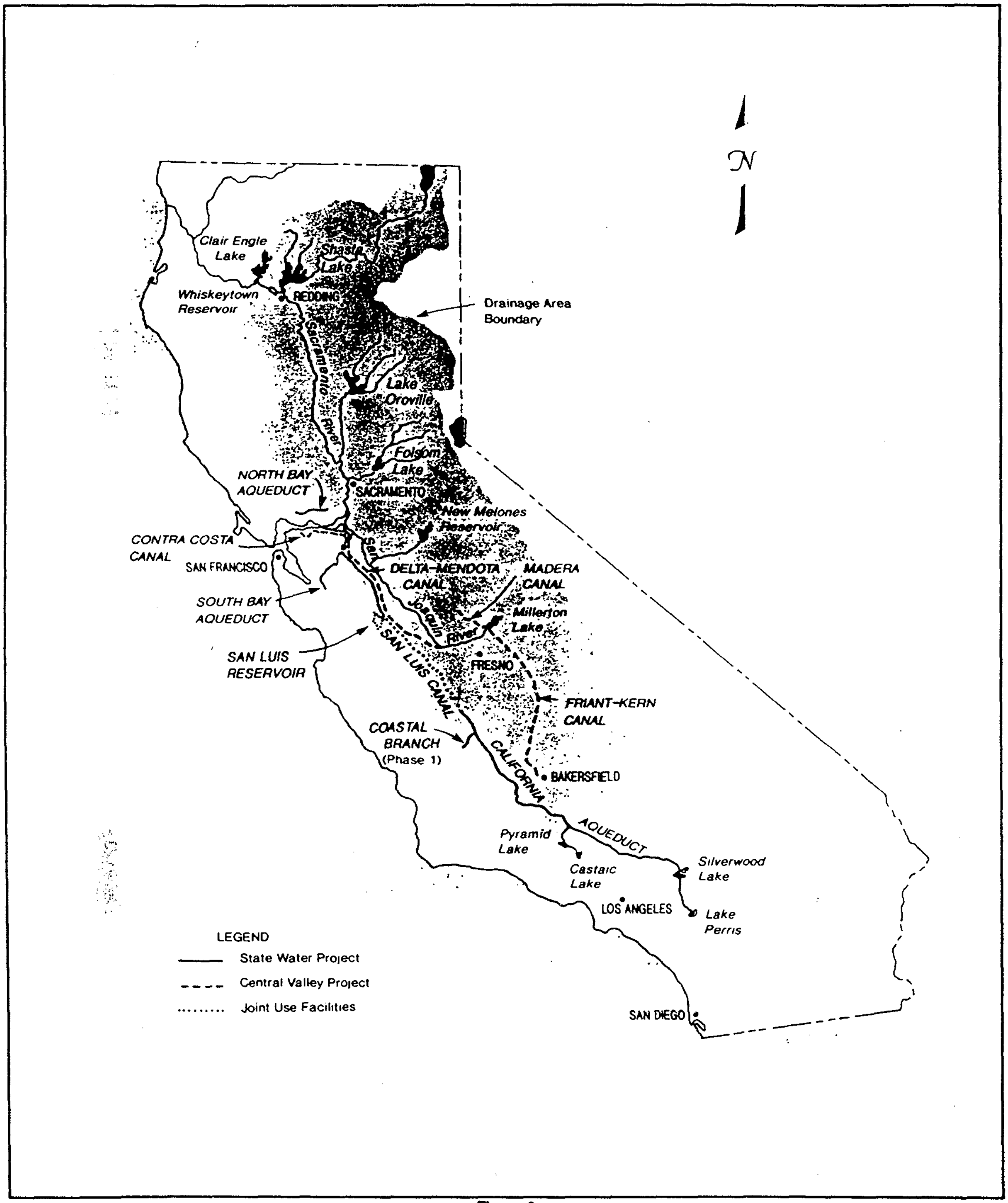

Figure 9
MAJOR FEATURES OF THE CENTRAL VALLEY PROJECT AND STATE WATER PROJECT

purpose of the fish facility is to reduce the amount of floating debris and number of fish conveyed to the pumps.

Banks Pumping Plant initial facilities (7 pumping units) were constructed in 1962. The plant was completed in 1992 with addition of four pumping units. The plant consists of 11 units: two rated at 375 cfs capacity, five rated at 1,130 cfs, and four rated at 1,067 cfs. Water is pumped into the California Aqueduct through five discharge lines ranging from 13.5 to 15 feet in diameter.

Average daily diversions are generally limited to 6,680 cubic feet per second, as set forth by U.S. Army Corps of Engineers criteria dated October 13, 1981. Diversions may be increased by one-third of San Joaquin River flow at Vernalis during mid-December to mid-March if that flow exceeds 1,000 cfs. The maximum diversion rate during this period would be 10,300 cfs, the nominal capacity of the California Aqueduct. Average monthly pumping rates are summarized in Figure 10.

Additional limitations on export pumping are imposed by Water Right Decision 1485.[1] During May and June, the maximum average monthly diversion rate is limited to 3,000 cfs, and July is limited to a maximum average rate of 4,600 cfs. Exports can be further reduced to a mean rate of 2,000 cfs during May and June if releases for export are exceeding natural inflow at Lake Oroville.[2]

Exports are also restricted under the long-term biological opinion for winter-run Chinook

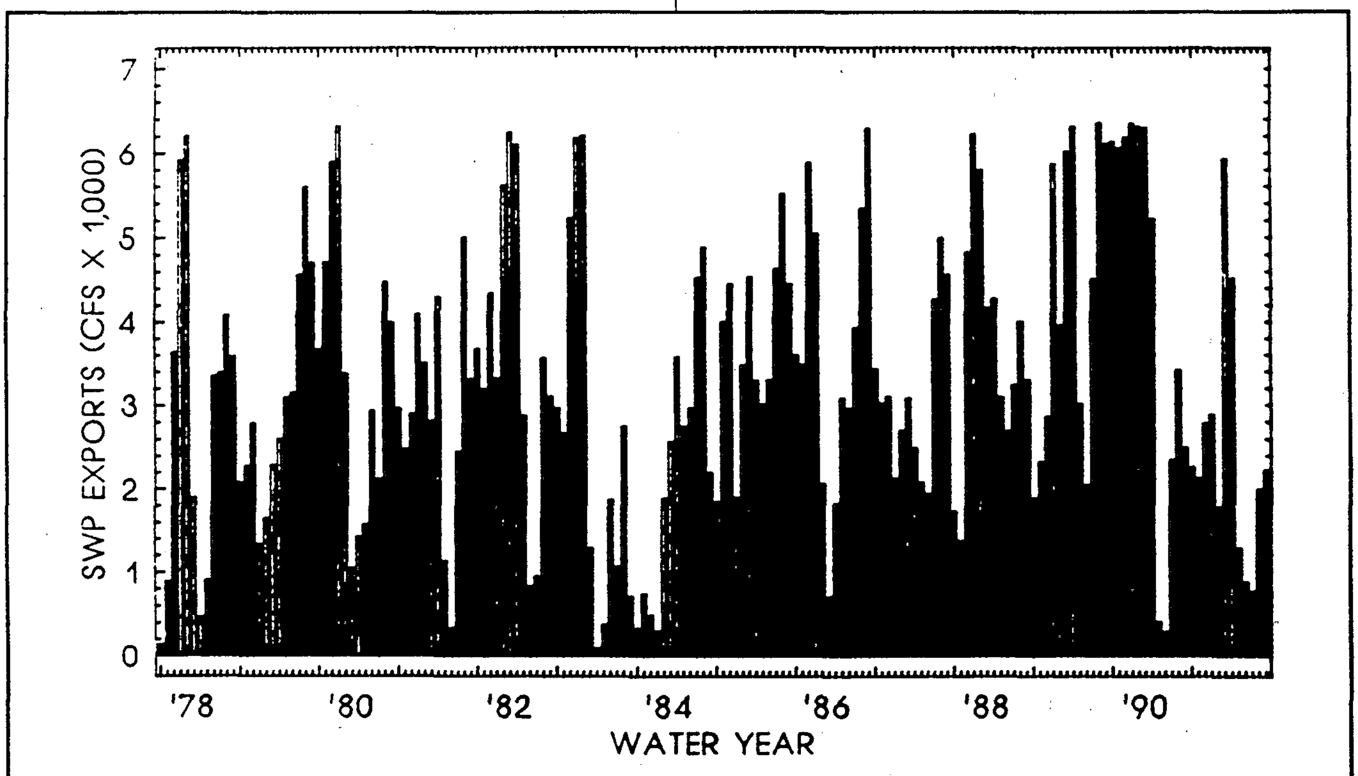

Figure 10
AVERAGE MONTHLY STATE WATER PROJECT PUMPING, WATER YEARS 1978 TO 1991
From the DAYFLOW Database

1 State Water Resources Control Board. Water Right Decision 1485: Sacramento-San Joaquin Delta and Suisun Marsh. August 1978.

2 This criterion is set forth in a letter dated January 5, 1987, from the California Department of Water Resources to the California Department of Fish and Game.

salmon and the 1993 opinion for delta smelt. These restrictions and other requirements of these opinions are discussed later in this chapter.

Typically, in average or above-average runoff years, Banks Pumping Plant would divert near allowable export rates during September and the first half of October to move water from Lake Oroville to San Luis Reservoir. A portion of late summer and fall capacity is used to wheel 195,000 acre-feet of water for the Central Valley Project to replace water not pumped during May and June in compliance with Decision 1485 criteria. In December through March, maximum export rates are generally required to capture uncontrolled runoff in the Delta to fill the SWP share (1,062 TAF) of San Luis Reservoir.

Entitlement water deliveries to SWP contractors are also maintained during these periods. Peak contractor delivery patterns during spring and summer are satisfied by direct diversions from the Delta in conjunction with releases from San Luis Reservoir and SWP reservoirs in Southern California. At times, unused Delta pumping capacity would be available to move additional water for direct delivery or into storage south of the Delta for future use.

Water Demands

Contracts executed in the early 1960s established the maximum annual entitlement water amounts each long-term contractor may request from the State Water Project. These annual quantities, known as Table A, reflect each contractor's projected annual water needs at the time the contracts were signed. Every September, each contractor must submit a request[1] to the Department of Water Resources for water delivery for the next 5 years. These 5-year projections form the basis for SWP planning and operation studies in the upcoming year. In 1993, contractor entitlement requests are about 3.8 million acre-feet. Maximum entitlement deliveries for long-term water contractors are 4.218 million acre-feet annually.

Basically, SWP water deliveries consist of two categories: agricultural and municipal/industrial. Water supply contracts provide for a maximum reduction in agricultural water deliveries of up to 50 percent in any one year without reductions in M&I deliveries. If cutbacks dictate agricultural shortages of more than 50 percent in one year, M&I users must share the amount above 50 percent. In addition, agricultural water deliveries may not be reduced by more than 100 percent in any seven consecutive years. Shortages above this amount must be shared equally between agricultural and M&I contractors.

Following are descriptions of other categories of water that could be pumped at Banks Pumping Plant (in addition to Table A entitlement water).

- ***Make-up water*** is a requested amount of entitlement water the State Water Project is unable to deliver at a given time. Contractors may elect to receive the undelivered water at other times during the year or in succeeding years, providing water and delivery capability are available.
- ***Unscheduled water*** is also water in excess of entitlement demands but is not scheduled in advance for contractor delivery. It is unstored water available in the Delta for export, as opposed to being released from project storage.
- ***Surplus water*** is water beyond that required to meet all entitlement demands and other commitments. Surplus water can be delivered to contractors when capacity is available. Surplus water may be released from storage and is scheduled in advance by contractors. Priority is given to agricultural use or ground water replenishment.

1 The requests cannot exceed a contractor's Table A allocations.

- *Wet-weather water* can be credited to South Bay or San Joaquin Valley contractors for use in the future in years when above-normal water supplies locally reduce the need for SWP water.
- *Regulated delivery of local supply* is a term used when SWP facilities are used to transport non-SWP water for long-term contractors under various agreements for local water rights.
- *Carryover water* is a portion of a contractor's current year entitlement that may be deferred until the following year. Under DWR policy, carryover water cannot affect the next year's water delivery approvals.
- *Wheeling* of non-SWP water through SWP facilities is done under a variety of arrangements for long-term contractors and for the Central Valley Project.

Water Allocation

Allocation of water supplies for a given year is based on four variables:

- Forecast water supplies based on the Sacramento River Index[1].
- Amount of carry-over storage in Oroville and San Luis reservoirs.
- Projected requirement for end-of-year carry-over storage.
- SWP system delivery capability.

These criteria ensure that sufficient water is carried over in storage to protect Delta water quality the next year, to meet fishery requirements, and to provide an emergency reserve.

Beginning in December each year, initial allocations of entitlement deliveries are determined based on the four criteria. Allocations are updated monthly until May, and more often if storms result in a significant increase in the Sacramento River Index.

Following is a chronology of the SWP water delivery allocation process.

- December.
  Initial allocations are made, based on operation studies using the four criteria and an assumed historical 90 percent exceedence[2] water supply.
- January and February.
  Allocations will not be reduced, even if water supply forecasts and operation studies indicate the initial allocation may be too high. Allocations may be increased if the water supply forecast (99 percent exceedence) and operation studies show delivery capability to be greater than forecast the month before.
- March.
  Allocations will be reduced if the supply is less than forecast in December. Allocations can be increased based on forecasted 99 percent exceedence water supplies.
- April and May.
  Allocations will not be reduced further unless operational storage and forecast runoff (99 percent exceedence) indicate carry-over conservation storage will fall below targeted minimums. Increases in water delivery allocations can be made based on improved 99 percent exceedence forecasts and supportive operational studies. Final allocations are based on the May water supply forecast.

1 The Sacramento River Index is the sum of measured runoff at four locations: Sacramento River near Red Bluff, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake.
2 Exceedence refers to the probability that a particular value will exceed a specified magnitude; for example, 90 percent exceedence means the water supply will be exceeded 90 percent of the time.

Central Valley Project Facilities, Capacity, and Demand

At Tracy Pumping Plant, about 5 miles north of Tracy, Central Valley Project water is lifted 197 feet into the Delta-Mendota Canal. The intake canal at this CVP facility includes Tracy Fish Screen, which intercepts downstream-migrant fish. The earth-lined intake channel to the Tracy Pumping Plant is 2.5 miles long.

Each of the six pumps at Tracy Pumping Plant is capable of pumping 950 cubic feet per second. Water is pumped through three 15-foot-diameter discharge pipes and carried about 1 mile to the Delta-Mendota Canal. Average monthly pumping rates are shown in Figure 11.

Tracy Pumping Plant flows can range from less than 1,000 cfs to a maximum capacity of almost 5,000 cfs. Maximum sustained rate is about 4,600 cfs, the nominal capacity of the first 13.7 miles of the Delta-Mendota Canal. Typical pump ing rates are between 4,000 and 4,600 cfs excep when restrictions are imposed by water ri or endangered species requirements. Regula tory requirements limit pumping rates to av entrainment of juvenile fish or species and stages of special concern. An example of pumping restriction is during May and J when Decision 1485 restricts pumping rate 3,000 cfs during critical striped bass spawnin periods. Pumping is also restricted w threatened winter-run salmon and delta sm are exposed to facility diversions.

To meet water contractor demands, Tr Pumping Plant is usually operated at or nea maximum capacity. Except during the p irrigation season, pumping may be limite the conveyance capacity of the Delta-Mendot Canal, or the re-lift capability (4,200 cfs O'Neill Pump/Generating Plant.

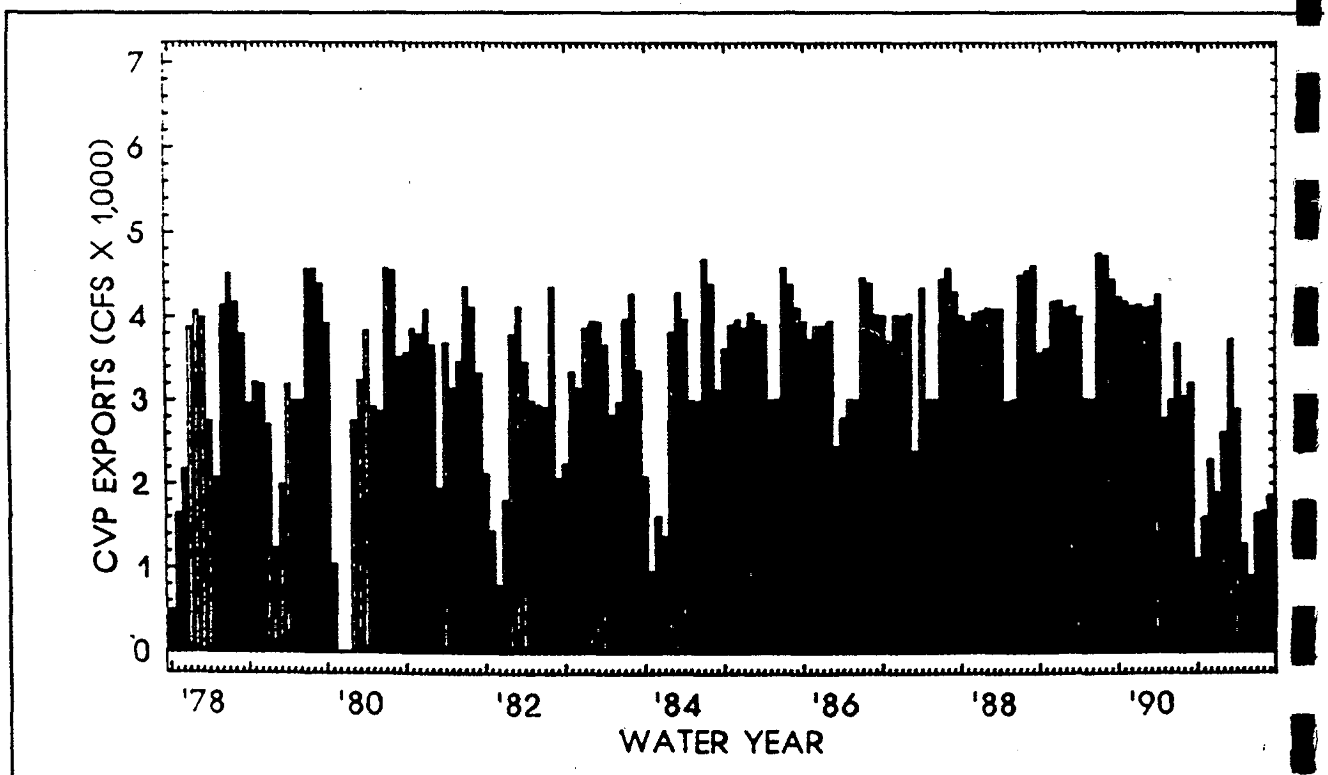

Figure 11
AVERAGE MONTHLY CENTRAL VALLEY PROJECT PUMPING, WATER YEARS 1978 TO 1991
From the DAYFLOW Database

About half the Central Valley Project water supply is delivered to the San Joaquin Valley through the Delta-Mendota Canal and San Luis Unit, but essentially all the water originates north of the Delta. To provide the water to contractors in the San Joaquin Valley, three things must be considered:

- Needs of water service contractors and exchange contractors.
- Plans for filling and drawing down San Luis Reservoir.
- Plan for coordinating Delta pumping and San Luis Reservoir use.

Operators also incorporate Delta-Mendota and San Luis operations into plans for operating CVP facilities in and north of the Delta.

Water Demands

In the San Joaquin Valley, the Central Valley Project supplies water to CVP water service contractors and San Joaquin River exchange contractors. Exchange contractors "exchanged" their senior rights to water in the San Joaquin River for a CVP water supply from the Delta. The Bureau of Reclamation guaranteed these contractors a firm annual water supply of 840,000 acre-feet, with a maximum reduction of 25 percent to 650,000 acre-feet in dry years. Water service contractors also receive water from the Delta, but reductions in their supplies can exceed 25 percent.

Entitlements of both types of contractors must be combined with the pattern of requests for water to operate the CVP efficiently. In many years, full water supplies and sufficient pumping capability are available to meet all demands. In some years, water deliveries are limited because of insufficient supply or conveyance capacity. Schedules of water deliveries and releases from the northern reservoirs must be coordinated with each other as well as with the Trinity, Sacramento, and American River operations of the Central Valley Project.

Water Allocation

In most years, the combination of carry-over storage and runoff into CVP reservoirs is sufficient to provide the necessary water and the operational flexibility to deliver the water. In this context, operational flexibility refers to the availability of water at the time it is needed, physical storage and conveyance capacity, and sufficient supplies and ability to control cold and warm water releases. The combination of these factors defines the limits of water allocation; the diverse water needs and their interrelationship determine specific allocations.

Providing the water needed for beneficial uses requires a strategy that recognizes two competing requirements: the need to retain sufficient carry-over storage to ensure temperature control capability and reduce risks of shortage, and the need to draw from storage in a given year to deliver sufficient water to avert health, safety, and economic hardship.

In normal or above-normal water years, it is usually possible to satisfy competing needs. Even in drier years, if normal carry-over storage is available at the beginning of the year, water allocations may be met partly by withdrawal from reservoir storage. However, all beneficial uses of CVP water are adversely affected during prolonged drought. Both environmental and economic systems are stressed by the cumulative impacts of dry conditions to a point where tolerance of continued drought is significantly weakened. When storage in CVP reservoirs at the beginning of the water year is diminished, capability of the system to mitigate the impact of continuing drought is also diminished.

Operation studies performed for the long-term CVP-OCAP[1], issued in October 1992, showed deficiencies on water deliveries at least as severe as those in the past and, in some cases, CVP agricultural allocations are reduced to zero.

Table 1 is a breakdown of CVP deliveries, by category of use.

Table 1
ANNUAL CENTRAL VALLEY PROJECT DELIVERIES, BY CATEGORY OF USE
(In Million Acre-Feet)

	Water Rights	Project Agriculture	M&I	Refuge
Delta	0.9	2.1	0.3	0.1
Sacramento Basin	2.2	0.4	0.2	0.1
Total	3.1	2.5	0.5	0.2

Water rights and M&I are subject to maximum 25 percent reduction in CVP-OCAP.

San Luis Reservoir and O'Neill Forebay

There are two ways to move water from the Delta to San Luis Reservoir. One is the CVP Tracy Pumping Plant, which pumps water into the Delta-Mendota Canal. The other is the SWP Banks Pumping Plant, which pumps water into the California Aqueduct. Operations of the CVP and SWP must be closely coordinated to avoid inefficient situations, such as one project pumping water into the reservoir at the same time the other is releasing water.

San Luis Reservoir is usually filled during winter and early spring to ensure that contractual obligations can be met through summer. Surplus, uncontrolled water in the Delta is pumped into the California Aqueduct and the Delta-Mendota Canal and flows by gravity to O'Neill Forebay. Here a portion of the flow is pumped into San Luis Reservoir and the remainder continues south to the San Joaquin Valley and Southern California. Beginning in May and continuing through summer, irrigation and urban requirements are substantially larger than the allowable Delta pumping, so water is released from San Luis Reservoir to satisfy requests from downstream water contractors.

Since San Luis Reservoir has little natural inflow, water must be stored when the two Delta pumping plants can export more water than is needed for contracted deliveries. Because the amount of water that can be exported from the Delta is limited, the fill and drawdown cycle of San Luis Reservoir is an extremely important part of both CVP and SWP operations.

A typical cycle starts with minimum reservoir storage at the end of August. Irrigation needs decrease in September, but the opportunity to begin refilling the reservoir depends on available water in the Delta and adequate capability at the Delta pumping plants. CVP pumping continues at the maximum until the end of April, unless San Luis Reservoir is filled or the Delta water supply is not available. In May and June, Decision 1485 standards limit export pumping, and irrigation needs begin to increase, so San Luis Reservoir storage begins to decline. In July and August, CVP pumping is again at the maximum, plus up to 195,000 acre-feet of CVP water can be exported at Banks Pumping Plant to replace water that could not be pumped at Tracy during the May/June pumping restriction. Irrigation demands are still high during this period, and San Luis storage continues to decline until late August, when the cycle begins anew.

It is important to coordinate scheduling of San Luis Reservoir operations between the two projects. When the State Water Project pumps water required by Decision 1485 for the Central Valley Project, it may be of little consequence

1 Operations Criteria and Plan.

to SWP operations but critical to CVP operations. The amount of water in San Luis Reservoir may make it possible to "exchange" space or water to aid the operations of either project. Also, close coordination is required to ensure that water pumped into O'Neill Forebay by the two projects does not exceed the CVP's capability to pump into San Luis Reservoir or into the San Luis Canal at the Dos Amigos Pumping Plant (Figure 12).

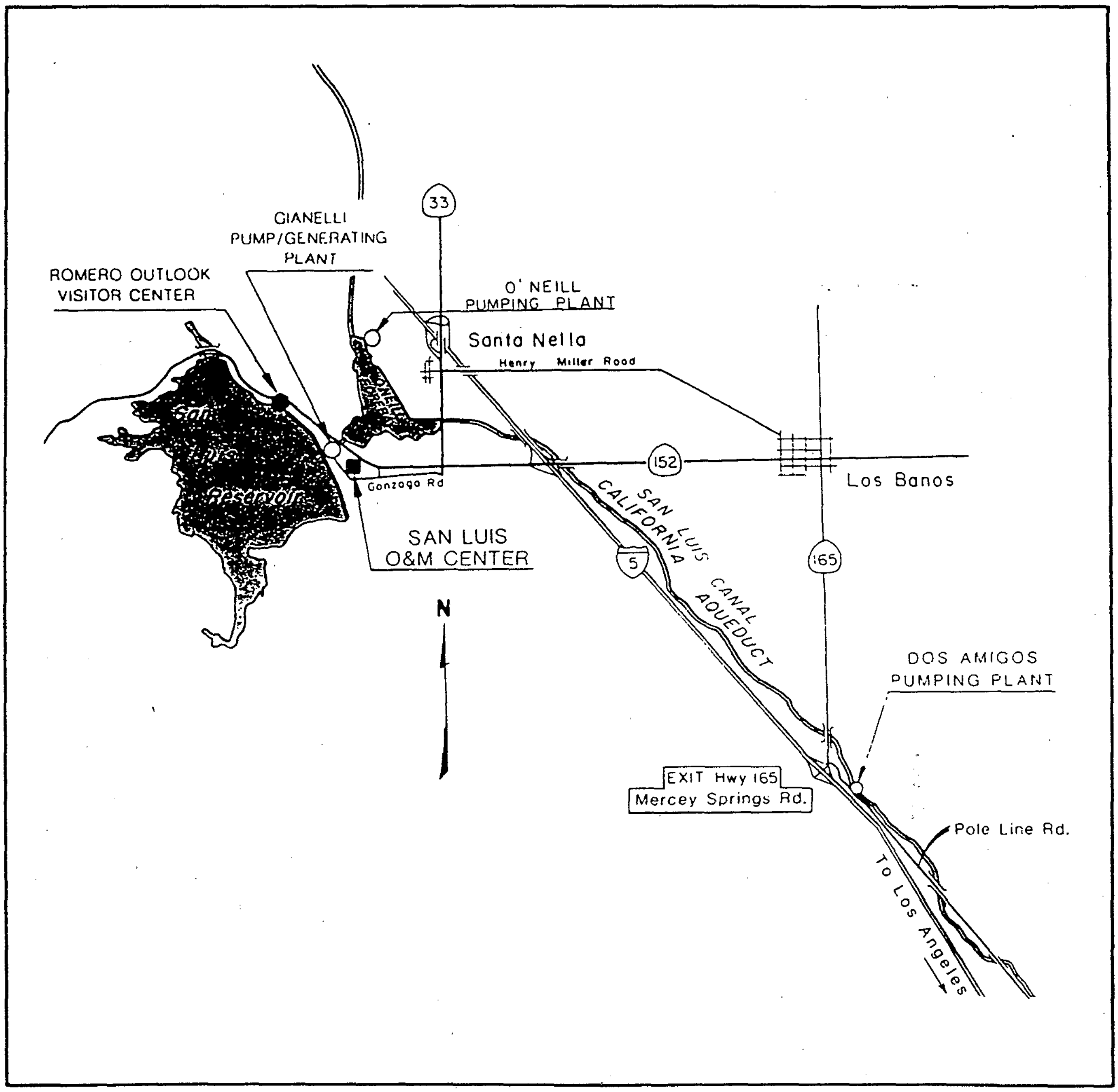

Figure 12
STATE WATER PROJECT AND CENTRAL VALLEY PROJECT JOINT FACILITIES AT
SAN LUIS RESERVOIR AND O'NEILL FOREBAY

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John E. Skinner Fish Protective Facility

The John E. Skinner Delta Fish Protective Facility began operating in 1968, using the same basic louver design as used at the CVP fish salvage facility. The louver system resembles venetian blinds and acts as a behavioral barrier. The slots are wide enough for fish to enter but, at the correct water velocities, fish encountering the screens sense the turbulence and move along the screen face to the bypass.

Screens at Skinner Fish Facility separate fish from water diverted to Banks Pumping Plant through Clifton Court Forebay. The system consists of a series of primary V-shaped bays with louver fish screens that guide fish to a bypass at the apex of the "V" (Figure 13). Fish entering the bypass move by buried pipeline to a secondary screening system, where they are further concentrated. Exiting the secondary by another bypass, the screened fish enter holding tanks, where they are kept until they are trucked into the Delta and released. The release sites, Horseshoe Bend and Curtis Landing, are far enough from the pumps to reduce chances of salvaged fish returning to the pumping plants. Releases are alternated between the two sites to reduce predation. Two CVP release sites are also available in emergencies.

In the early 1980s, the Department of Water Resources modified Skinner Fish Facility by installing center walls in the primary bays to improve striped bass screening efficiency; opening new bays; building a new, perforated-plate screened secondary; and rescreening the holding tanks to help minimize fish losses. The

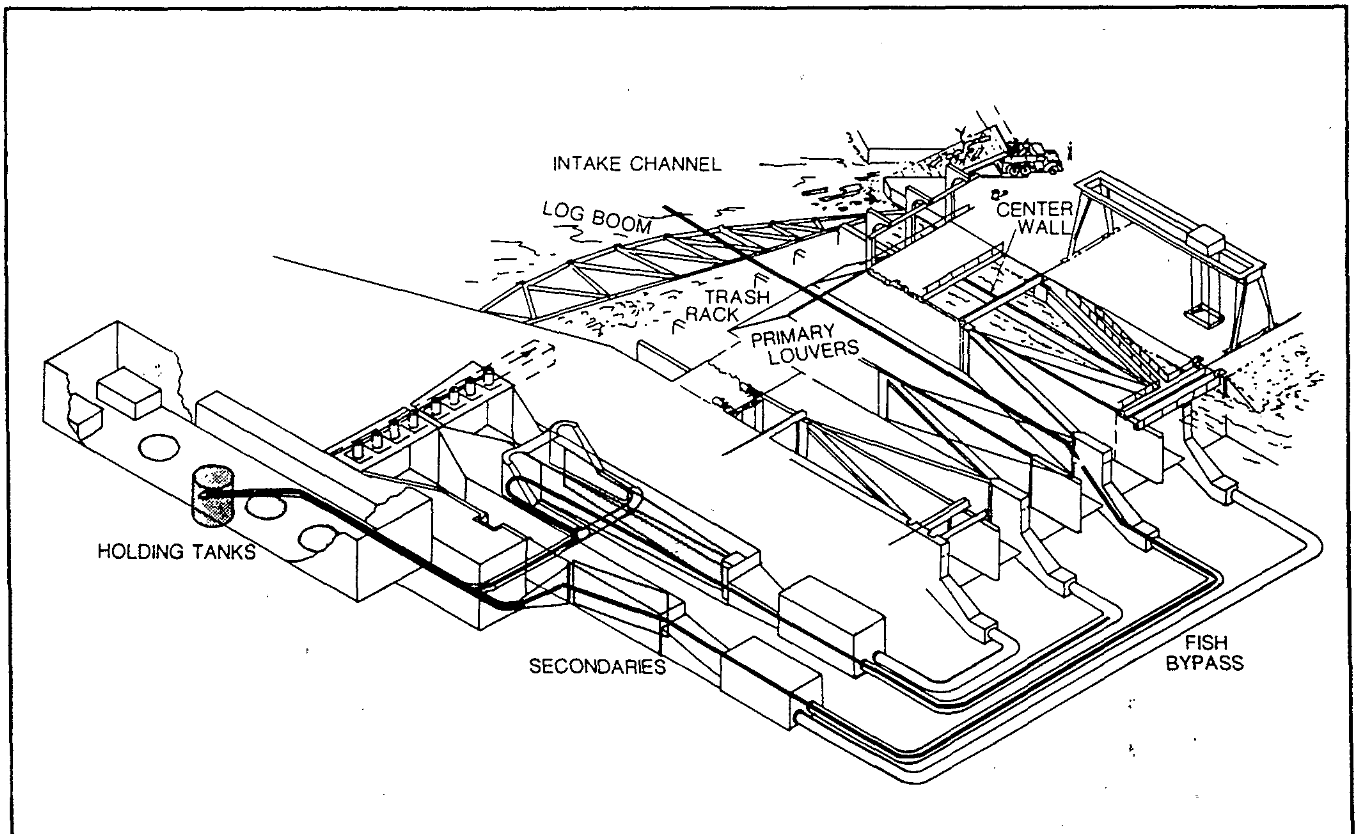

Figure 13
SCHEMATIC DIAGRAM OF THE JOHN E. SKINNER FISH PROTECTIVE FACILITY

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new secondary is a positive-barrier screen, in that the small-diameter perforations prevent most fish greater than 20-mm TL from passing through the screen. This screen type is not designed to reduce entrainment of eggs or larvae.

In 1992, Water Resources completed three more holding tanks at the Skinner facility, which improve salvage efficiency for some species by allowing more efficient use of both secondary systems. In addition, the four new pumps at Banks Pumping Plant, in combination with the new holding tanks, allow better velocity control and increased salvage efficiency. The increased efficiency results from the capability to optimize water velocities for these species at any given pumping rate and from using both secondaries to ensure that flows through the holding tanks do not exceed fish protective criteria.

Fish salvaged at Skinner Fish Facility are subsampled periodically to obtain information on species composition, numbers, and lengths.

Since operation of Skinner Fish Facility began in 1968, the number and species composition of fish salvaged has been estimated by subsampling the fish entering the holding tanks. In 1992, the Department of Fish and Game took over the fish salvage and sampling operation under a contract with the Department of Water Resources. Fish and Game maintains the salvage data and reports monthly salvage estimates.

In the early 1970s, the Department of Water Resources and Department of Fish and Game conducted an extensive evaluation of Skinner Fish Facility and have subsequently evaluated specific features such as trucking and handling losses, predation losses in Clifton Court Forebay, and losses in the holding tanks. Studies have generally been confined to a relatively few species of fish, including fall-run Chinook salmon, striped bass, and American shad. No specific studies have been conducted for delta smelt. However, recent experience of Fish and Game and the University of California, Davis, in handling and hauling delta smelt caught in the estuary indicates delta smelt probably experience high delayed mortality due to stress during handling and trucking of the SWP and CVP fish salvage programs.

Following are descriptions of each major feature of the SWP fish salvage system in the southern Delta, with special reference to delta smelt.

Clifton Court Forebay Gate Operations

Clifton Court Forebay is a 31,000-acre-foot regulating reservoir at the intake to the California Aqueduct (Figure 14). Inflows to the forebay are controlled by radial gates and are generally operated during high tides to reduce

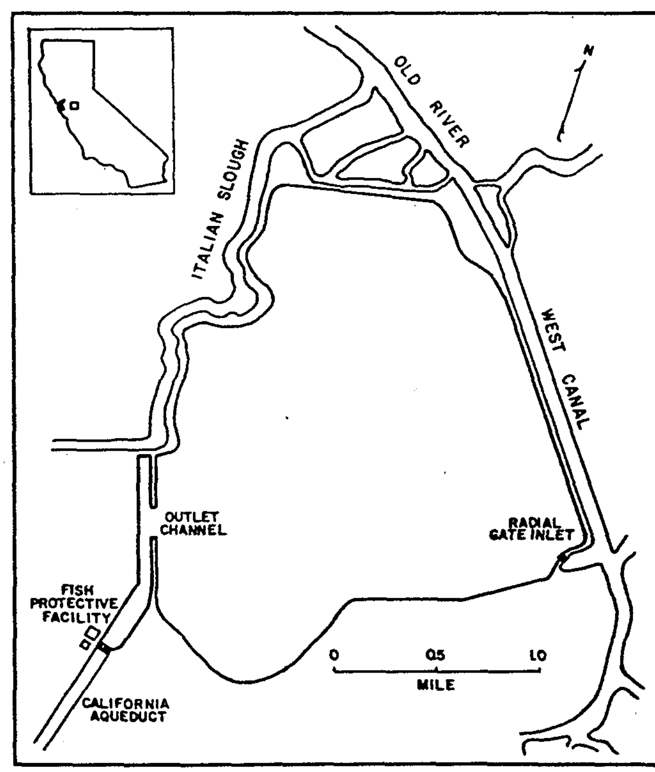


Figure 14
CLIFTON COURT FOREBAY

approach velocities and prevent scour in adjacent channels. The forebay is operated to minimize water level fluctuation in the intake by taking water in through the gates at high tides and closing the gates at low tides. When the gates are open at high tides, inflow can be as high as 15,000 cubic feet per second for a short time, decreasing as water levels inside and outside the forebay reach equilibrium. This flow corresponds to a velocity of about 2 feet per second in the primary intake channel. Figure 15 shows operation patterns of the radial gates, and Figure 16 shows the gate operation schedule, representing expected operations. The schedule may vary from actual operations, depending on pumping restrictions for winter-run Chinook or other species of concern.

Predation in Clifton Court Forebay, a significant source of juvenile fish mortality, has been evaluated based primarily on juvenile salmon survival across the forebay. In a series of Fish and Game studies, losses of marked fall-run hatchery salmon and striped bass crossing the forebay were significant. Losses were assumed to be largely due to striped bass predation, since the population of subadult striped bass in the forebay have been estimated to range between 35,000 and 945,000 (T. Tillman, DFG, pers comm; Kano 1990). Fish and Game is using a juvenile salmon loss rate of 75 percent to calculate Chinook salmon losses at the State Water Project intake.

No predation studies have been conducted in the forebay to evaluate prescreen loss rates for delta smelt.

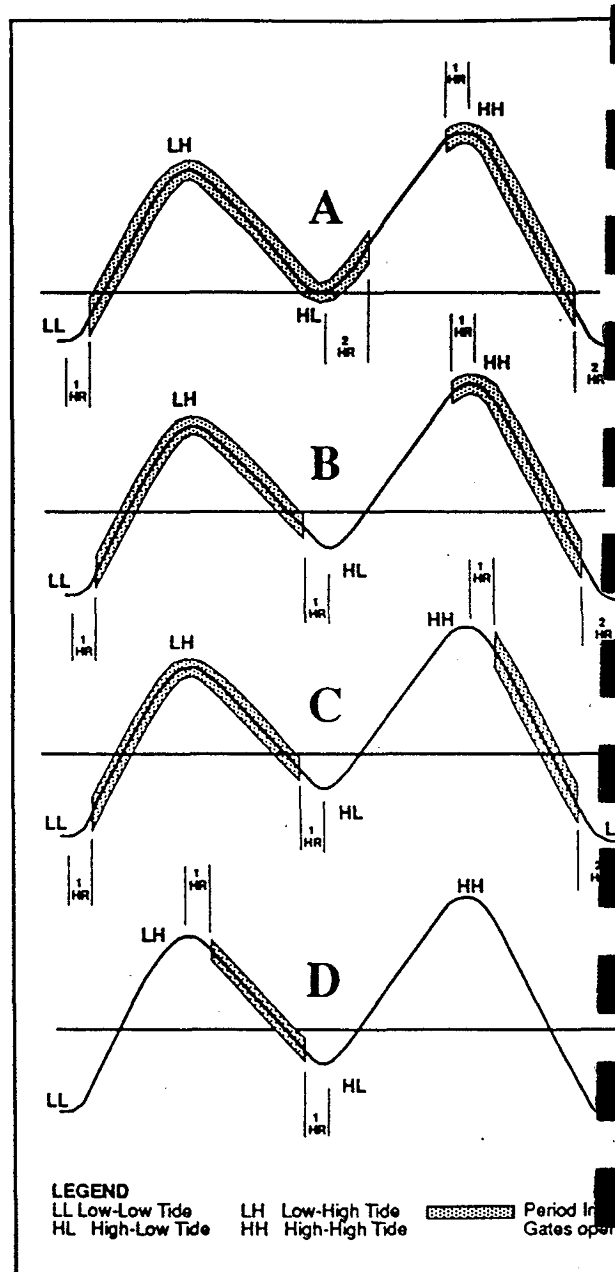


Figure 15
OPERATION PATTERNS OF
CLIFTON COURT FOREBAY RADIAL GATES

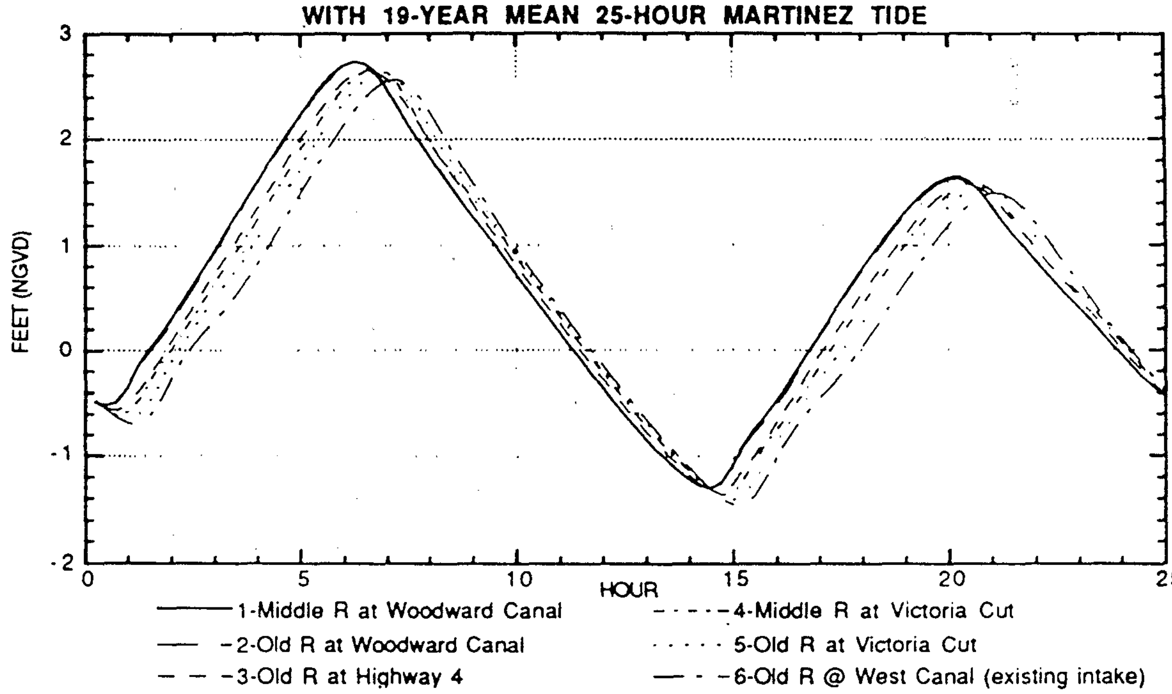
Primary and Secondary Louvers

Louver and screen efficiency studies have been proposed for delta smelt; however, due to difficulty handling smelt and their poor survival in captivity, the Interagency Program's delta smelt work group is discussing interim criteria based on current efficiency rates and use of surrog species for swimming stamina studies. T University of California, Davis, is unde tract to Water Resources to study delta sm swimming stamina and environmental ances. This information will help esta screening requirements and flow velocity lim

PHASE II GATE OPERATION

GATE OPERATION	TIMING
OPEN	1 HOUR BEFORE HIGH-HIGH TIDE
CLOSE	2 HOURS BEFORE LOW-LOW TIDE
OPEN	1 HOUR AFTER LOW-LOW TIDE
CLOSE	1 HOUR BEFORE HIGH-LOW TIDE

TIDES AT FOREBAY INTAKE LOCATIONS WITHOUT SWP EXPORTS WITH 19-YEAR MEAN 25-HOUR MARTINEZ TIDE



GATE OPERATION SCHEDULE

LOCATION	MODEL NODE	TIME IN HOURS OPEN	CLOSE	OPEN	CLOSE
1	117	5.00	12.25	15.25	24.25
2	82	5.00	12.25	15.25	24.25
3	79	5.25	12.50	15.50	24.50
4	113	5.50	12.50	15.50	24.50
5	75	5.75	12.75	15.75	24.75
6	72	6.00	13.00	16.00	25.00

Figure 16
CLIFTON COURT FOREBAY GATE OPERATION SCHEDULE

Salvage efficiencies for salmon, striped bass, and American shad were evaluated in 1974 at the Skinner Fish Facility. As a result, the following equations for combined efficiency of primary and secondary louver screens for the species of interest were derived.

<u>Length *(mm)*</u>	<u>Efficiency</u>
Fall-Run Chinook Salmon	
1-100	0.630 + (0.0494 x Approach Velocity)
100	0.568 + (0.0579 x Approach Velocity)
Striped Bass	
21-30	0.935 – (0.149 x Approach Velocity)
31-40	0.806 – (0.0431 x Approach Velocity)
>41	0.945 – (0.0717 x Approach Velocity)
American Shad	
1-50	(–65.8) – (0.0539)(Length^2) + (5.43)(Length)
>51	0.71

Screen efficiency is a function of fish length and channel velocities. Decision 1485 specifies the following velocities in both the primary and secondary channels:

- 3.5 feet per second from November 1 through May 14 for Chinook salmon.
- 1.0 foot per second from May 15 through October 31 for striped bass.

Channel velocity criteria are also a function of bypass ratios through the facility. Decision 1485 requires the following bypass ratios for salmon and striped bass.

For salmon:

- » Maintain 1.2:1.0 to 1.6:1.0 bypass ratio in both primary and secondary channels.

For striped bass:

- » Maintain 1.2:1.0 bypass ratio when operating Bay A only.
- » Maintain 1.2:1.0 bypass ratio when operating Bay B only.
- » Maintain 1.5:1.0 bypass ratio when operating both primary bays and when channel velocities are less than 2.5 fps.
- » Maintain 1.2:1.0 bypass ratio in the secondary channel for all approach velocities.

How delta smelt react to these velocities or whether any of the criteria are appropriate for juvenile or adult smelt is not known.

The new secondary is a perforated-plate positive-barrier screen with 5/32-inch holes. The screen will exclude 100 percent of salmon longer than about 20 mm. With appropriate channel (sweeping) and screen approach velocities, screening efficiency could also be this high for juvenile or adult delta smelt, depending on swimming ability and size. Efforts are now directed at determining approach velocities for delta smelt from the swimming stamina studies and screen mesh size from morphometric measurements.

Striped bass and other predators can accumulate in the primary and secondary channels and prey on smaller fish moving through the salvage facilities. Periodic dewatering of these channels reduces predator accumulation.

In June 1990, the secondary screening channels at Skinner Fish Facility were drained to collect fish that had not entered the bypass and holding tanks. A total of 494 fish, representing 18 species, were salvaged. Among the species were:

Prickly sculpin	258
Striped bass	99
Chinook salmon	27
American shad	24
White catfish	11
Delta smelt	2

There are no reliable estimates of delta smelt losses to predation in this part of the system, but the potential for predation on delta smelt exists.

The Department of Water Resources has evaluated secondary bypass flows to assess bypass efficiencies under various operation criteria (D. Hayes, DWR, pers comm). Velocities in the bypass under existing striped bass flow criteria are not optimal to transport larger strong-swimming fish through the bypass into the holding tanks. Designs are being reviewed to test modifications of the bypass entrance which would increase flow velocities from the secondary channel into the bypass. With these modifications, bypass efficiencies should increase significantly for larger, stronger predators such as striped bass and white catfish. The increased bypass efficiency should, therefore, reduce predation losses in the secondaries for all species of fish.

Holding Tanks

The holding tanks were rescreened in the mid-1980s to prevent physical loss of fish diverted into the tanks. Decision 1485 specifies 10 cfs maximum flow through the holding tanks. This criterion can be met with the six holding tanks, although, due to flow imbalances, the criterion is met by average flows of 10 cfs into each tank.

To remove fish from the holding tanks, they are collected in a crane-supported transfer bucket and moved to a tanker truck for hauling to the release sites.

A number of factors influence short-term and long-term survival of fish in the holding tanks, including but not limited to:

- Predators.
- Stress related to extended periods of forced swimming against holding tank currents (a function of tank water levels).
- Salvage and handling.
- Water quality and temperature.

In 1984 and 1985, tests were conducted to determine mortality associated with handling and trucking fish salvaged at Skinner Fish Facility (Raquel 1989). Six species of fish were studied: Chinook salmon, striped bass, American shad, steelhead trout, threadfin shad, and white catfish. Mortality varied widely, depending on species, size of fish, and water temperature. Holding tank temperature and dissolved oxygen were the parameters most often significantly correlated with handling mortalities. Holding tank flow, dissolved oxygen, and holding tank and trucking water temperatures were the parameters most often significantly correlated with trucking mortalities.

During salvage operations, however, delta smelt in good condition are seen regularly, swimming in the holding tanks or loading buckets just before being loaded onto the transport trucks (J. Morinaka, DFG, pers comm). University of California, Davis, researchers have collected delta smelt from the loading buckets but have had limited success at holding or transporting these fish to their laboratory for studies.

The Bureau of Reclamation will evaluate the relationship between holding times and mortality rates for several fish species at the Tracy Fish Facility in 1994. The Department of Water Resources will study those results for applicability to SWP operations.

Counting and Measuring Delta Smelt

Since it is impractical to count all salvaged delta smelt, estimates are made by subsampling periodically during the day and extrapolating results to the entire day. Typically, subsamples are collected every 2 hours by diverting flow from the secondary bypass into a "counting" tank. Sampling time varies with expected fish density but is normally about 10 minutes. Fish collected in each subsample are identified to species, counted, and returned to the holding tank. Four times each day (at 0300, 0900, 1500, and 2100), the total length of each species from each subsample is measured to the nearest millimeter. Total daily salvage, by species and average length of each species, is then calculated by comparing the period subsampled with the total pumping time.

As part of the contract between UC-Davis and Water Resources to define environmental and screening criteria for delta smelt, recent efforts have been focused on morphometric measurements of preserved and live specimens of delta smelt. Preserved specimens were obtained from UC-Davis, the Bureau of Reclamation, and Dr. J. Wang. Live smelt from samples at the SWP and CVP salvage facilities are measured when available. The measurements will help define the size of the screen opening necessary to exclude a given life stage based on average morphometric dimensions. These data will be used in developing overall screening criteria for delta smelt.

Hauling

Two stainless steel tank trucks operate at Skinner Fish Facility. Both are specially designed to reduce mortality associated with transporting fish to the release sites. The 2,500-gallon and 1,200-gallon tanks reduce overcrowding, provide better temperature insulation, and are designed and loaded to reduce sloshing during transport. The smaller tank is fiberglass insulated to help keep the water cool, and both tanks have oxygen injection systems.

Hauling frequency is based on estimated density of fish in the holding tanks. Guidelines for operating Skinner Fish Facility require that fish not be held longer than 8 hours, so salvaged fish are hauled to release sites at least three times a day. When large numbers of fish are collected, hauls can be as frequent as five or six times a day. Also, hauls may be more frequent if only one truck is available, especially when operating only the 1,200-gallon truck.

Effects of handling and hauling on several fish species at Skinner Fish Facility were evaluated by Raquel (1989). Recommendations include adding 2 to 10 ppt salt to water in the tank trucks to reduce physiological stress of handling. Adding salt increased overall survival during transport (Raquel 1989). Currently, 5 ppt of salt is added to the tank water before transport (J. Morinaka, DFG, pers comm).

Although the studies did not specifically include delta smelt, data from Raquel (1989) are being reviewed for relevance to delta smelt survival. Delta smelt are apparently intolerant of handling and have high mortality rates under physically demanding conditions (Odenweller 1990, 1991; Sweetnam and Stevens 1991; R. Mager, UCD, pers comm).

There have been related concerns regarding long-term survival of salvaged delta smelt following release (Odenweller 1990, 1991; Sweetnam and Stevens 1991). Effects of transport and handling on survival of delta smelt have been documented during striped bass grow-out facility operations. Of 1,605,774 fish taken from the salvage facility to the grow-out facility in 1989, 111,093 did not survive; that number includes all of the 2,590 delta smelt taken incidentally (Odenweller 1990). Again in 1990, all 14,475 delta smelt taken were lost at the grow-out facility (Odenweller 1991). However, it is not clear how conditions at the grow-out facility compare to those salvaged fish experience when returned to Delta waters.

Additional handling and trucking stress studies of delta smelt or a surrogate species are being proposed (Sweetnam and Stevens 1991; D. Hayes, DWR, pers comm).

Salvage Release Sites

The State Water Project maintains two permanent release site facilities, at Horseshoe Bend on the Sacramento River and on Sherman Island at Curtis Landing on the San Joaquin River. Two CVP release sites are also available in emergencies.

Releases are alternated between sites over a 24-hour period. Normally, morning releases are at the Curtis Landing site, evening or night releases are at Horseshoe Bend, and afternoon releases are alternated between sites. Night releases are always at Horseshoe Bend because of protective fencing around the truck hookup. During delta smelt salvage operations in 1993, trucks made up to five releases a day to reduce holding times and exposure to predators in the holding tanks and in the trucks.

The 1993 delta smelt biological opinion requires the Department of Water Resources to construct an additional site for salvaged fish releases. A thorough environmental evaluation of permanent release site options and obtaining the necessary permits could not be completed by the January 1, 1994 deadline. Therefore, Water Resources proposed modifying one of its tank trucks so releases could be made at a number of suitable sites without requiring immediate construction of an additional permanent release structure without adequate environmental analysis. In this way, an additional release site can be operational by the January 1, 1994, deadline.

As part of evaluations of predation impacts on released fish, Reclamation, Water Resources, and Fish and Game are planning a hydroacoustic and gill-netting study. The study will compare predator densities at the permanent release sites under normal release operations to predator densities at multiple locations with infrequent releases. This evaluation was proposed to determine if permanent release facilities were returning fish to the Delta without creating additional losses due to predation. The study is planned for spring 1994 and 1995. Results will be compared to studies by Pickard *et al* (1982) on predator composition at release sites to identify any changes in predator abundance or composition.

Tracy Fish Protective Facility

The Bureau of Reclamation completed Tracy Fish Protective Facility in 1958 to salvage fish that would otherwise be lost to Tracy Pumping Plant or entrained into the Delta-Mendota Canal. Tracy Fish Facility is a louver structure based on a design developed by the U.S. Fish and Wildlife Service (Bates and Vinsonhaler 1956) and was the first full-scale louver fish screen ever built. The purpose of the louver structure was to intercept and salvage salmon smolts and 4-inch and larger striped bass.

Tracy Fish Facility is at the intake to Tracy Pumping Plant, 2.5 miles downstream. The basic features of Tracy Fish Facility are the system of primary and secondary louvers (Figure 17). The primary screening system is a single 320-foot-long louver array positioned at about a 15-degree angle to the direction of the flow. The louver slats are 25 feet high with a 1-inch space between slats. Four 6-inch "bypass windows" along the primary louver face convey the fish to the secondary louvers and on to the holding tanks. The salvaged fish are transferred to 2,000-gallon trucks and hauled to the Delta for release. The Bureau of Reclamation currently uses two release sites, one on the Sacramento River near Horseshoe Bend and the other on the San Joaquin River immediately upstream of the Antioch Bridge.

Changes in water surface elevation caused by tidal fluctuations affect operations at Tracy Fish Facility. High tides at Tracy Fish Facility occur about 8 hours after high tide at the Golden Gate Bridge, and tidal heights are about 70 percent less than at the Golden Gate. Typical tidal fluctuation at the fish facility is about 3 feet; maximum fluctuations are 6 feet. Since pumping at Tracy is generally constant over a 24-hour period, channel and approach velocities vary with tidal height.

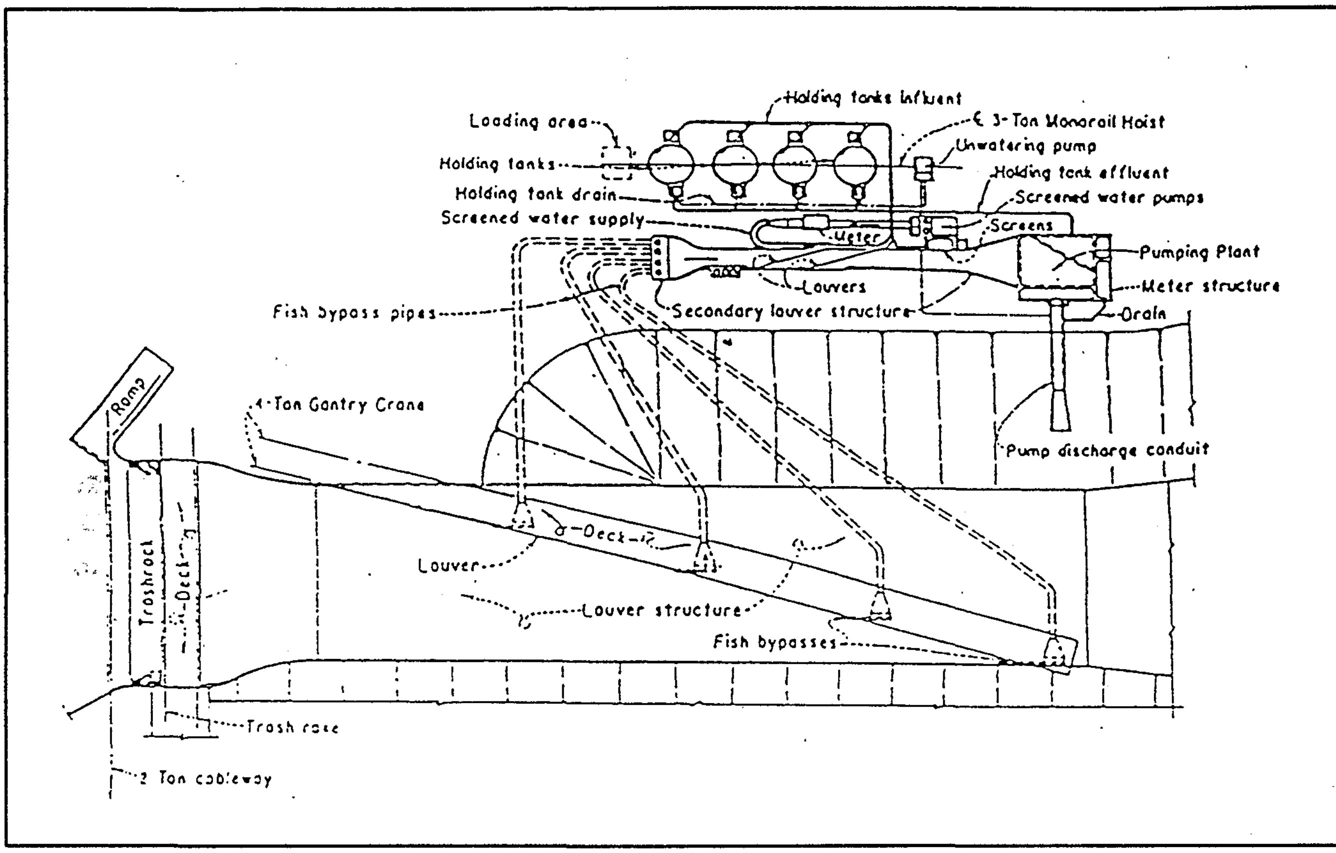


Figure 17
SCHEMATIC DIAGRAM OF CENTRAL VALLEY PROJECT TRACY FISH PROTECTIVE FACILITIES

The fish facility is operated to achieve water velocities through the louvers as specified in Decision 1485 for striped bass (about 1 foot per second) and for winter-run salmon (about 3 fps). However, tidal changes in water surface elevation can make this operation difficult, especially during low tides.

When Tracy Fish Facility began operating, Tracy Pumping Plant was not operated year-round. Water was pumped to meet seasonal irrigation demand, generally April through October. With addition of San Luis Reservoir in 1967, Tracy Pumping Plant and Tracy Fish Facility became a year-round operation. Pumping through winter affected fish species other than salmon and striped bass, especially smelt and other early spawners. This is documented by increased salvage of these species at the fish facility.

A complete field evaluation of the facility is now underway to identify specific operational problems and possible improvements. The Bureau of Reclamation is also evaluating hydraulic conditions at the fish facility and periodically removing predators from the secondary bypass system.

Primary and Secondary Louvers

Initial evaluations of the Tracy Fish Facility were conducted in the late 1950s by the U.S. Fish and Wildlife Service (Bates *et al* 1960) and California Department of Fish and Game (Hallock 1968). The first study was not designed to measure efficiency at the primary louvers, but it did show a 90 percent salvage efficiency in the secondary louvers. The second study used paired fyke nets upstream and downstream of the primary louvers and, based on striped bass, found that the primary louvers had a 71 percent efficiency in 1966 and a 91 percent efficiency in 1967. The difference between years was due to the size of captured striped bass. Data with striped bass showed a diversion efficiency of 5.4 percent for bass averaging 20 mm, 76 percent for bass averaging 32 mm, 92.4 percent for bass averaging 44 mm, and 99.4 percent for bass longer than 120 mm.

In day-versus-night comparisons, the primary louvers appeared to be more efficient during daylight hours, but the difference was minimal. At velocities of 2.2 to 3.9 feet per second, no significant difference in efficiency could be documented. Numbers of other species captured in this study were too small to accurately determine louver efficiencies. From preliminary estimates, it appears that primary louver efficiency was 66 percent for delta smelt (161 observed), 89 percent for threadfin shad (159 fish), and 91 percent for American shad (1,223 fish). This 66 percent louver efficiency for delta smelt probably reflects a predominance of adults and sub-adults in the collections. Louver efficiencies seem to be species or size dependent, based on these data. Further research is needed to document salvage efficiencies for delta smelt at Tracy Fish Facility.

The current study to improve operations at Tracy Fish Facility will examine how the facility functions in relation to listed and candidate species, especially delta smelt. Discussions are continuing to determine interim screen criteria based on existing efficiency rates and to define surrogate species for stamina studies to develop specific delta smelt criteria.

Striped bass, white catfish, and other predators in the primary and secondary channels undoubtedly prey on delta smelt. There are no reliable estimates of predation loss rates for smelt, but loss rates for smolt salmon are estimated at 15 percent based on losses at other fish screens.

For the last 3 years, the Bureau of Reclamation has removed predators from the secondary louver channel on a monthly basis. Large numbers of predators have been removed, and the number and size of predator fish seems to be decreasing with successive removal operations.

Stomach analyses of striped bass and white catfish indicate small fish are the major food consumed. A few delta smelt have been found in the stomachs of predators removed from the secondary channel.

The Bureau of Reclamation plans to continue monthly predator removal from the secondary channel to reduce predation on smaller fish such as delta smelt. The Bureau also plans to study ways to reduce predators in front of the trash rack and in the primary louver channel.

Holding Tanks

There are two types of losses in the holding tanks, neither of which has been documented. The first type is predation losses, similar to those in the louver channels. The second type is loss due to stress and fatigue from fighting a current for long periods. Both types would increase as length of holding time increased. The 1993 biological opinion for delta smelt requested holding times of no more than 8 hours to help reduce these losses. The Bureau of Reclamation complied with this request before release of the opinion and continues to do so.

There is concern that delta smelt do not reach the release sites alive and that salvage operations are ineffective for this species. Bureau of Reclamation personnel have indicated that delta smelt survive the screening and holding procedure and are in good shape when placed into transport trucks. Adult delta smelt are generally seen in the loading bucket, in groups of 5 to 10 near the surface. Studies are needed to confirm that existing salvage operations are functioning properly or to design new methods to improving delta smelt survival through the salvage facilities.

The Bureau of Reclamation has proposed a study to determine how holding time influences mortality rates for several fish species. However, documenting the health or condition of fish before they enter the holding tanks will be difficult. The added handling stress involved in determining their condition before they enter the holding tank will affect interpretation of results. Initial work on this study is proposed to begin in 1994.

Counting

It is not practical to count all salvaged fish, so estimates are made by sampling every 2 hours and extrapolating the results to the entire day. Sampling typically represents one-twelfth of the total salvage. Lengths of fish are measured at two counts every day. Counting and identifying fish results in additional handling, so these fish are more stressed than the typical fish going through the salvage operations.

When salvage operations began at Tracy Fish Facility, salmon and striped bass were the species of interest, and delta smelt were lumped in a class of fish called "others". When enumeration of smelt began in the 1960s, longfin and delta smelt were both in one category, "smelt", but the two species have since been identified separately.

A concern with the data is that delta smelt may have been misidentified in these early years. Adult delta smelt are fairly easy to identify, and identification has likely been accurate for many years. Larval delta smelt closely resemble longfin smelt, and until recently it was not possible to separate the two species. Juvenile delta smelt can also be easily confused with juvenile threadfin shad and American shad. Positive identification at these younger stages cannot be done without preserving them, which would be counterproductive for a salvage facility.

The Bureau of Reclamation has hired a fisheries biologist expressly for Tracy Fish Facility and has contracted with a consultant as part of a long-range improvement of taxonomic identification for several fish species. Studies so far indicate fish facility workers are nearly 100 percent accurate at identifying adult delta smelt and about 80 percent accurate at identifying juvenile longfin and delta smelt. Salvage personnel are not expected to become proficient at identifying larval smelt less than 15 mm. This work will be done by a contractor.

Hauling

Hauling losses for delta smelt are unknown at this time. Stress and predation are the obvious concerns. The large hauling trucks (2,000 gallons) are built and loaded in such a way as to reduce sloshing. These large tank trucks are believed to provide the best conditions for transport of fish that can reasonably be developed. Tests have shown that water temperature changes are less than one degree in the hottest part of summer. In addition, salt is added to the tanks to create a 5 parts per thousand solution to reduce stress and disease associated with handling and transporting fish.

Hauling fish in tanker trucks during foggy weather is a major problem. Because of dense fog in the Delta during winter, often for long periods, personnel safety is a concern. These conditions also increase the time of the hauling trip, exposing delta smelt to additional stress and predation potential.

Salvage Release Sites

The 1993 delta smelt biological opinion indicated that Tracy Fish Facility had a single release site for salvaged fish, because the other site had a non-functional pump and was under repair. At a June 2, 1993, meeting, a representative of the U.S. Fish and Wildlife Service Endangered Species Office indicated that completing repairs at the second release site would fulfill the requirement for an extra CVP stocking site. Repairs have been completed, and two fish release sites are now being used.

During the winter of 1992-93, thousands of adult delta smelt were salvaged at the CVP and SWP fish facilities. These smelt were moving from rearing areas near the confluence of the Sacramento and San Joaquin rivers to upstream spawning areas and were drawn to the export pumping plants. Once salvaged, the fish were returned to the existing release sites in the lower Delta and had to repeat the upstream migration.

The Bureau of Reclamation is proposing to acquire a third fish release site, which would be designed for use by both the CVP and SWP trucks. The third site would be chosen and designed exclusively to enhance the salvage and survival of delta smelt. The third release site would allow release of delta smelt near their spawning areas. This would reduce the chances of salvaged delta smelt being re-entrained by the salvage facilities and would place them closer to known spawning areas.

The Department of Fish and Game and the Bureau of Reclamation have discussed locating the third site near the Rio Vista bridge, in the northern Delta. A recent relocation of Highway 12 has made an ideal area for fish release. An additional release site could be completed in about a year and a half.

Suisun Marsh Facilities

Suisun Marsh in in southern Solano County, west of the Delta and north of Suisun Bay (refer to Figure 1, in Chapter 1). This tidally influenced marsh is a vital wintering and nesting area for waterfowl of the Pacific Flyway, and it represents about 12 percent of California's remaining wetland habitat.

The *Suisun Marsh Plan of Protection*[1] and *Suisun Marsh Preservation Agreement*[2] were developed to assure that a dependable water supply is maintained in the Suisun Marsh to offset diversions by the Central Valley Project, State Water Project, and others.

Suisun Marsh facilities will be operated to minimize marsh salinity only so far as operations do not create a need for additional upstream water releases, do not limit exports, do not harm fish, do benefit wildlife habitat, and do not require the Suisun Marsh Salinity Control Gate flashboards to remain in place beyond the time otherwise required to meet standards.

Figure 18 is a map of the Suisun Marsh. Areas for compliance with the revised Decision 1485 salinity standards are being phased in over time; monitoring at the first set of compliance sites started in October 1988, and the last site is to come on line in October 1997. Since October 1988, compliance has been required for the eastern and northeastern regions of the marsh at Collinsville (C-2), National Steel (S64), and Beldons Landing (S49).

1 In 1984, the Department of Water Resources published the *Plan of Protection for the Suisun Marsh including Environmental Impact Report* in response to Order 7 of Decision 1485.

2 The U.S. Bureau of Reclamation, Department of Water Resources, Department of Fish and Game, and Suisun Resource Conservation signed the *Suisun Marsh Preservation Agreement* in 1987.

The schedule for future compliance is:

- October 1993 — Western marsh channels at Chadbourne Slough at Chadbourne Road (S-21) and Cordelia Slough at Cordelia-Goodyear Ditch (S-97).
- October 1994 — Southwestern marsh channels at Goodyear Slough, 1.3 miles south of Morrow Island Ditch (S-75).
- October 1997 — Suisun Slough, 300 feet south of Volanti Slough (S-42).

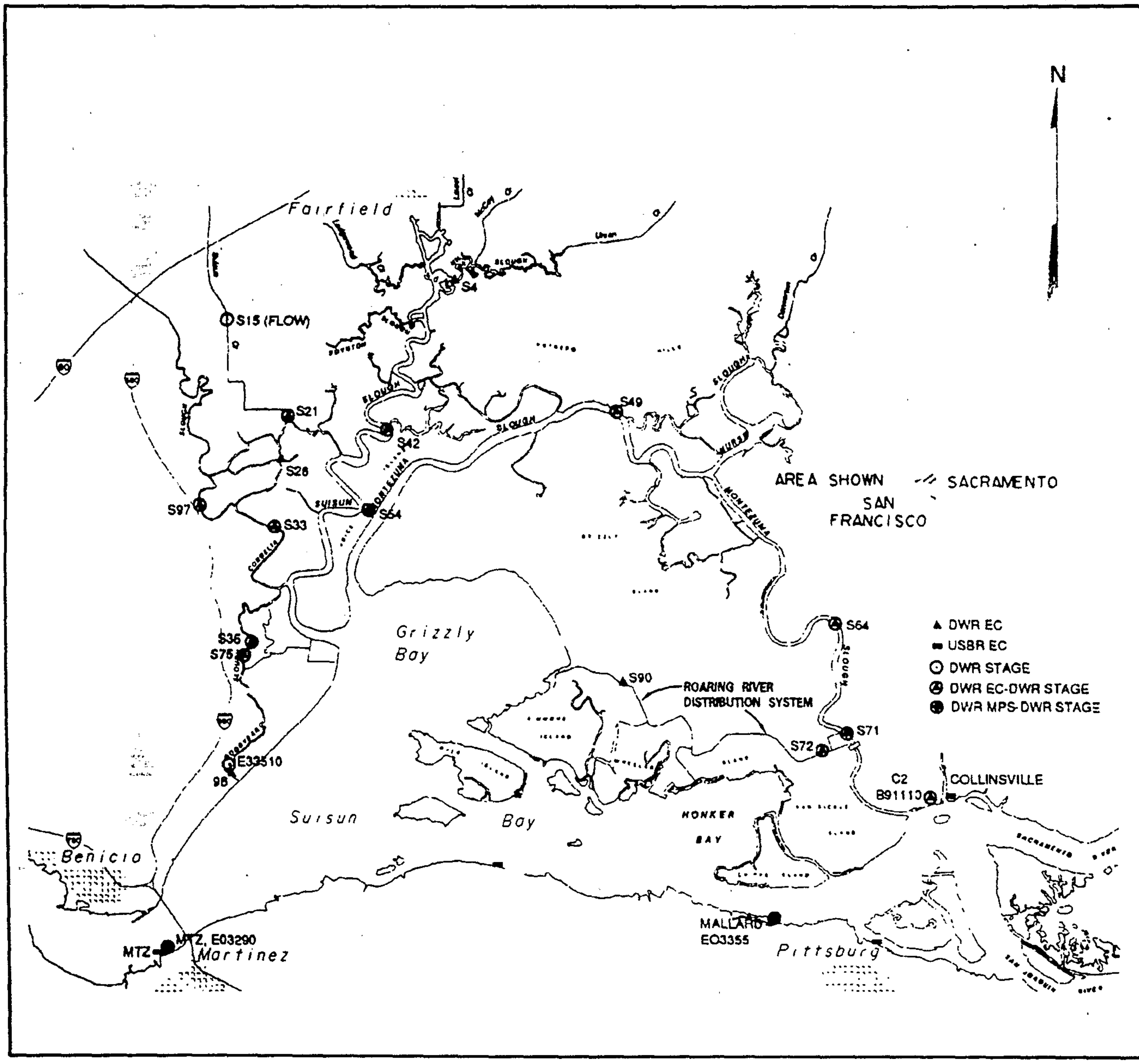


Figure 18
SUISUN BAY AND SUISUN MARSH

Phase I, Initial Facilities, of the Plan of Protection was completed in 1980 and Phase II, Suisun Marsh Salinity Control Gates[1], began operating in November 1988. Phases III and IV have been combined into the Western Suisun Marsh Salinity Control Project. Environmental documentation for the project is a joint effort by Bureau of Reclamation and Department of Water Resources, and a draft EIS/EIR is scheduled for October 1995. Phase V will provide a dependable water supply for the Grizzly Island region; project planning and environmental documentation work is scheduled to begin after the conclusion of the Phase III/IV project. Phase VI, Potrero Hills Ditch, will be initiated if tests indicate additional salinity control is necessary.

The objective of the Western Suisun Marsh Salinity Control Project is to restore and maintain western Suisun Marsh as a primarily brackish marsh capable of producing high-quality feed and habitat for waterfowl and other marsh wildlife. The objective will be realized when salinities in western marsh sloughs meet the standards specified in the SWRCB's water rights Decision 1485.

The Department of Water Resources will start meeting northwestern marsh salinity standards on October 1, 1993. If salinity control can be achieved, then northwestern marsh standards may be met independent of Suisun Marsh Salinity Control Gate operation and within the time set in Decision 1485. If water year 1994 is as dry as water year 1990, then an estimated continuous flow of 50 cubic feet per second of fresh water will be needed for January, February, and March and 30 cfs for April and May 1994 to meet Decision 1485 standards in northwestern marsh channels.

In planning for the Western Suisun Marsh Salinity Control Project, the Department of Water Resources and Bureau of Reclamation have scheduled a test to determine if releases of North Bay Aqueduct water will provide salinity control in the northwestern marsh. North Bay Aqueduct water will be used to augment natural flow in Green Valley Creek, which enters the marsh near the junction of Interstate Highways 80 and 680 at Cordelia, in Solano County. Data collected during the test will provide information for the EIS/EIR on the project, and the test itself will meet salinity standards until permanent actions are in place.

The test will be most useful if hydrologic conditions[2] are dry. If conditions are above normal or wet, then the Bureau of Reclamation and Department of Water Resources will schedule the test for the following year (September 1994 through September 1995).

Facilities of the Suisun Marsh Plan of Protection that could affect delta smelt are discussed in the following sections. Two other factors in the marsh could also affect delta smelt: diversions by private landowners, and the Lower Joice Island fill/drain facility. These are also discussed.

Suisun Marsh Salinity Control Gates

Suisun Marsh Salinity Control Gates are about 2 miles northwest of the eastern end of Montezuma Slough, near Collinsville. The structure spans Montezuma Slough, a width of 465 feet. A schematic of the structure (Figure 19) shows the southern, or upstream, side. From left (west) to right (east), the structure consists of the following components:

1 Also referred to as Montezuma Slough salinity control gates.
2 Hydrologic conditions are based on Decision 1485 water year classification criteria.

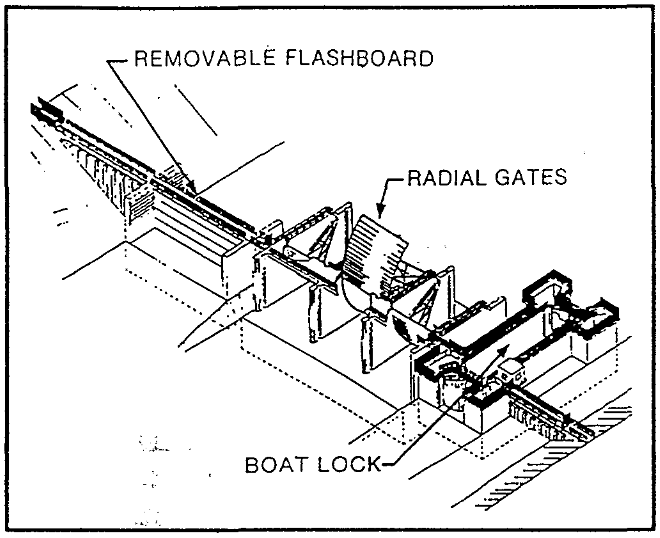


Figure 19
SUISUN MARSH SALINITY CONTROL GATES

- A permanent barrier, 89 feet across, extending from the western levee to the flashboard module.
- The flashboard module, which provides a 66-foot-wide maintenance channel through the structure that can be closed September 1 through May 31. The flashboards can be removed if emergency work is required downstream of the gates, but removal requires a large barge-mounted crane.
- The radial gate module, 159 feet across, containing three radial gates, each 36 feet wide.
- The boat lock module, 20 feet across, which is operated when the flashboards are in place.
- A permanent barrier, 131 feet across, extending from the boat lock module to the eastern levee.

An acoustic velocity meter is located about 300 feet upstream (south) of the gates to measure water velocity in Montezuma Slough near the structure. Water levels recorders on both sides of the structure allow operators to determine the difference in water level above and below the gates. The three radial gates open and close automatically, using the water level and velocity data.

The Suisun Marsh Salinity Control Gates are operated from October 1 through May 31 (the "control season") to divert fresher water from the Sacramento River near Collinsville into eastern end of Montezuma Slough and prevent more saline Grizzly Bay water from entering the western end. Gate operation is necessary during the control season of below-normal, dry, and critical water years. The gates can be operated full time to divert the maximum quantity of water from the Sacramento River or intermittently to divert only the quantity needed to meet Decision 1485 standards.

During full operation, the gates open and close twice each tidal day (about 25 hours). The gates are open during the ebb tide, when the water level is higher on the Collinsville (upstream) side, and remain open about 7 hours. The gates are closed during the flood tide, when water in Montezuma Slough begins to flow upstream toward Collinsville.

The quantity of flow pumped by the gates according to the tides is primarily a function of the shape and sequence of ocean tides and hydrologic conditions in the Delta. When the gates are operating, flows past the gates vary from no flow when the gates are closed to several thousand cubic feet per second with all three gates open. During round-the-clock operation, the net flow through the gates is about 1,800 cfs when averaged over one tidal day. When the gates are not operating (June through September) and the flashboards are removed, net flow in Montezuma Slough over one tidal day is low, and often in the upstream direction (as estimated by hydrodynamic model simulations). Water is diverted from Montezuma Slough at individual diversion points onto Fish and Game and private land along the slough and at the Roaring River Distribution System intake.

In spring 1992, the biological opinion for winter-run Chinook salmon dramatically changed operation of the Suisun Marsh Salinity Control Gates over that which would have normally occurred in a critically dry year. The gates were ordered closed from March 1 through March 27. Full gate operations were allowed beginning March 27, as long as individual owners did not divert through unscreened diversions. Since Roaring River is the only screened intake, most duck clubs were unable to take water until May 1, 1992, when permit conditions in the opinion ceased to be in effect.

Due to the new western Suisun Marsh salinity compliance sites (S-21 and S-97), the Department of Water Resources expects to operate the Suisun Marsh Salinity Control Gates "full bore" from September 17, 1993 through May 31, 1994.

Roaring River Distribution System

The Roaring River distribution system is one of the initial facilities of the *Plan of Protection*. The Roaring River diversion and distribution system intake is the largest diversion point off Montezuma Slough. The distribution system consists of eight 60-inch intake culverts just to the north of the original Roaring River Slough confluence with Montezuma Slough. A 40-acre intake (peaking) pond, constructed for the new intake culverts, supplies water to Roaring River Slough. Flows through the culverts into the pond are controlled by motorized slide gates on the Montezuma Slough side and flap gates on the pond side. The motorized gates are adjusted depending on tide levels, the amount of diversions off Roaring River Slough, and season. The original confluence of Roaring River Slough consists of a manually-operated flap gate that allows the slough to drain water for flood protection. This drain is privately owned and operated.

Water is diverted into Roaring River intake pond on high tides to raise the normal water surface elevation in Roaring River Slough above the adjacent marshlands. Wetlands south and north of Roaring River Slough then receive water from the slough at a steady flow, as needed. The pond is used to supplement the water supply in Roaring River Slough. In most cases, the wetlands continue to drain to Grizzly, Suisun, and Honker bays using existing facilities. Wetland management operation scenarios and water demand from Roaring River and Montezuma Slough are discussed in the next section, "Discrete Diversions from Montezuma Slough".

The new intake to Roaring River Slough is screened to prevent entrainment of fish larger than about 25 mm. The Department of Water Resources designed and installed the screens using Department of Fish and Game criteria. The Bureau of Reclamation and Department of Water Resources provide routine screen maintenance.

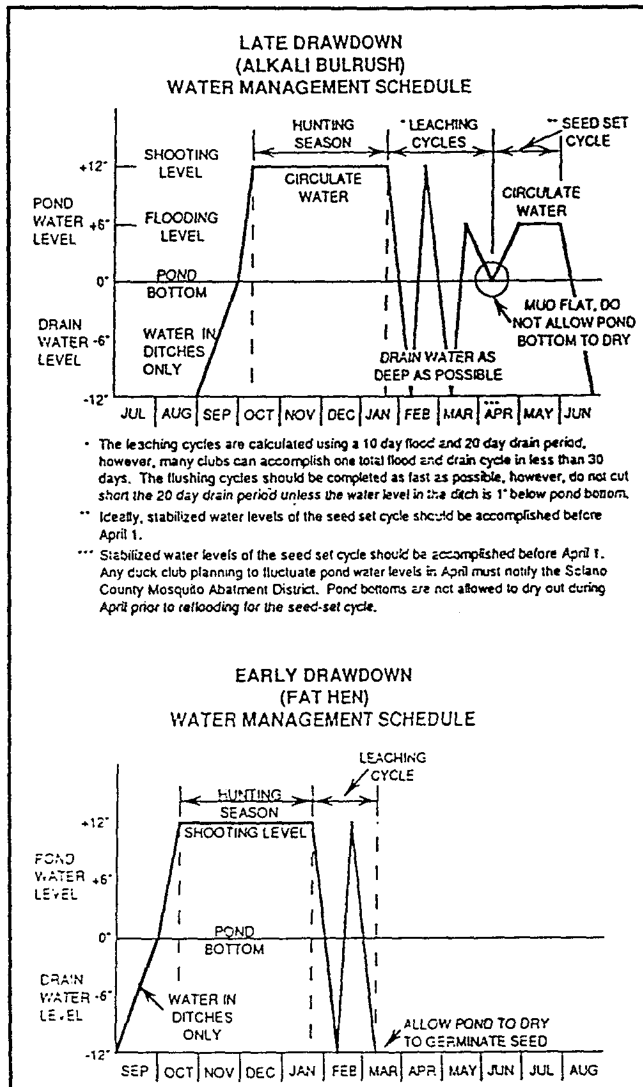
The screen is a stationary, vertical screen constructed of continuous slot, stainless steel wedge wire. One screen panel is constructed of copper-nickel alloy as a test of anti-biofouling materials (D. Hayes, DWR, pers comm). All screens have 3/32-inch slot openings. Design approach velocity is 0.5 foot per second, the through-screen velocity specified by the Department of Fish and Game to protect juvenile salmon and striped bass, but during routine operation velocity is usually below this value. Flow through the fish screen is controlled by motorized slide gates on each culvert (maximum design flows occur only at high-high tide, with all slide gates open).

Discrete Diversions from Montezuma Slough

The Department of Fish and Game and more than 30 private owners along Montezuma Slough divert water from the slough through more than 60 unscreened culverts of varying diameters. Most of these diversions are used to convert adjacent land areas to ponds for waterfowl management and hunting. Diversion rates are usually highest during October, when the managed wetlands are flooded for the first time that year. Initial flooding requires about 2 weeks.

Water management practices vary greatly in Suisun Marsh, but the Suisun Resource Conservation District is working to establish and enforce efficient management schedules for the private owners. During the control season, water is diverted from Montezuma Slough during initial flooding in October, for water circulation from November through mid-January, and during leach cycles from February through May (Figure 20).

The Department of Water Resources may screen the diversions from Montezuma Slough in the next two years. In 1994, DWR will install screens for culverts diverting water onto Grizzly Island Wildlife Refuge to offset losses of fish at Banks Pumping Plant. DWR is also considering screens for two culverts at the Lower Joice Island Fill/Drain Facility by 1995.



[*Rollins*, 1981]

Figure 20
TWO OPERATIONAL SCENARIOS FOR MANAGED WETLANDS IN SUISUN MARSH

Delta Cross Channel and Georgiana Slough

The Delta Cross Channel is a gated diversion channel constructed in 1951 by the Bureau of Reclamation to augment the natural transfer of water from the Sacramento River near Walnut Grove into the central and southern Delta. Water diverted from the Sacramento River into the Delta Cross Channel flows into Snodgrass Slough, then the Mokelumne River, the San Joaquin River, and various channels in the central and southern Delta, thus providing a more direct path for high quality Sacramento River water to the pumping plants in the southern Delta. The Cross Channel gates are also operated for fish protection, flood control, water quality control, and recreational boat traffic.

Flows into the Delta Cross Channel are controlled by two 60-foot by 30-foot radial gates located at the Sacramento River end of the

1-mile-long cross channel. In accordance with Decision 1485, the gates are closed to avoid diverting salmon whenever the daily Delta Outflow Index exceeds 12,000 cfs between January 1 and April 15. From April 16 through May 31, the gates may be closed for up to 20 days, at the discretion of Fish and Game, to avoid diverting striped bass if the Delta Outflow Index exceeds 12,000 cfs. Such closures may be for no more than 2 out of 4 consecutive days.

The Delta Cross Channel gates are also closed when flows in the Sacramento River at Sacramento exceed about 25,000 cfs to reduce scour on the downstream side of the gate structure and to limit high flows and velocities that might otherwise occur on the Mokelumne River side of the Cross Channel. On occasion, the gates may be operated to regulate flow in the Sacramento River to help meet the Decision 1485 salinity standard at Emmaton.

The "reasonable and prudent alternatives" contained in the biological opinion for Chinook salmon require closure of the Delta Cross Channel gates from February 1 through April 30 to avoid diversion of juvenile winter-run Chinook salmon. Also, the gates must be operated to minimize diversion of juvenile winter-run based on real-time monitoring for their presence in the lower Sacramento River from October 1 through January 31.

Georgiana Slough, just south of the Delta Cross Channel, is a natural Delta channel and, by virtue of its location, is the main channel for water that moves from the Sacramento River to the San Joaquin River, central Delta, and ultimately to the pumping plants in the southern Delta.

Contra Costa Canal

The Contra Costa Canal, which began operations in 1940 and was completed in 1947, originates at Rock Slough, about 4 miles southeast of Oakley. Water for irrigation and municipal and industrial use is lifted 127 feet by a series of four pumping plants. The 47.7-mile canal terminates in the Martinez Reservoir. The initial diversion capacity is 350 cubic feet per second, which gradually decreases to 22 cfs at the terminus. Historically, pumping has ranged from about 50 to 250 cfs, and varies seasonally (Figure 21). Two short canals, Clayton and Ygnacio, are integrated into the system.

The Bureau of Reclamation and Contra Costa Water District, along with the National Marine Fisheries Service and U.S. Fish and Wildlife Service, are developing a monitoring program to determine whether fish species of concern are being entrained into Contra Costa Canal and, if so, the levels of entrainment. Of principal concern are winter-run Chinook salmon and delta smelt, with slightly lesser concerns for Sacramento splittail and longfin smelt. The monitoring program is scheduled to begin by 1994.

When originally built, Contra Costa Canal had a fish screen at its entrance. It has since been removed, probably because it prevented fish from using 4 miles of canal before the first pumps were encountered. Biologists likely believed the unrestricted rearing habitat and production of fish in the 4 miles of canal below the pumps was more valuable than a fish screen to prevent losses. Section 3406(b)(5) of the Central Valley Project Improvement Act requires construction and operation of fish screening and recovery facilities to mitigate for fishery impacts resulting from operations of Contra Costa Canal Pumping Plant No. 1.

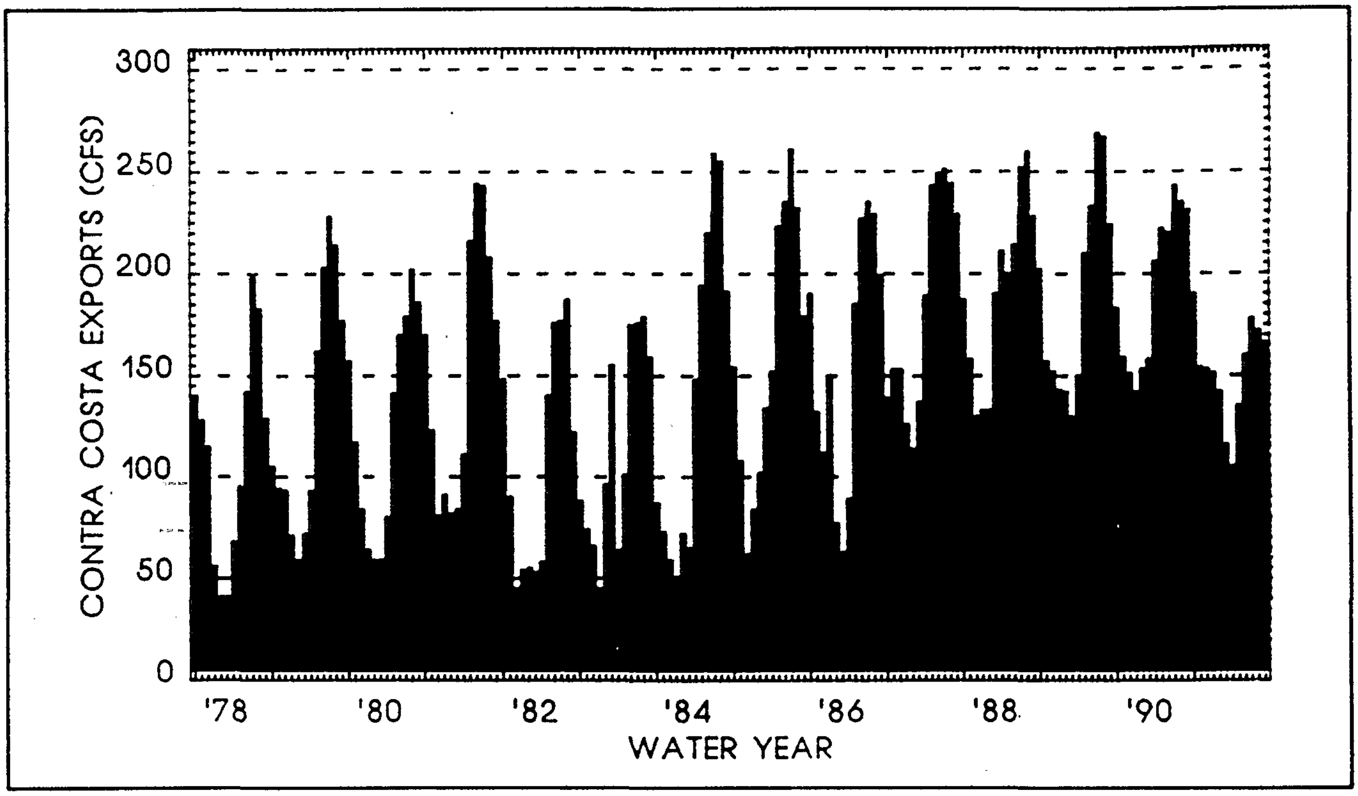


Figure 21
AVERAGE MONTHLY CONTRA COSTA CANAL PUMPING, WATER YEARS 1978 TO 1990
From the DAYFLOW Database.

North Bay Aqueduct

In 1987, the State Water Project began pumping from Barker Slough through the North Bay Aqueduct to meet project entitlements in Napa and Solano counties (see Figure 1, in Chapter 1). Ultimate scheduled annual deliveries are expected to be about 67,000 acre-feet. Maximum pumping capacity is about 175 cubic feet per second (pipeline capacity). Daily pumping rates have ranged between 0 and 90 cfs (Figure 22). The average annual pumping rate is 35 cfs.

Water diversion to the North Bay Aqueduct has improved water clarity and dissolved oxygen and decreased specific conductance due to downstream water being drawn into the Barker/Lindsey Slough complex (Kano 1990). Pumping rates could increase by 30 to 50 cubic feet per second in dry years when additional water may be needed to help meet new water quality standards in western Suisun Marsh.

In response to fisheries concerns, the Department of Water Resources constructed a state-of-the-art positive barrier fish screen at the Barker Slough intake. The screen consists of a series of flat, stainless steel, wedge-wire panels with a slot width of 3/32 inch designed to exclude fish 25 mm or larger from being diverted. A low approach velocity (0.5 feet per second) prevents them from being impinged onto the screens. The screens are routinely cleaned to prevent head loss across the screen face, which would result in increased approach velocities. Screen design and maintenance were developed in cooperation with and final design approved by the Department of Fish and Game.

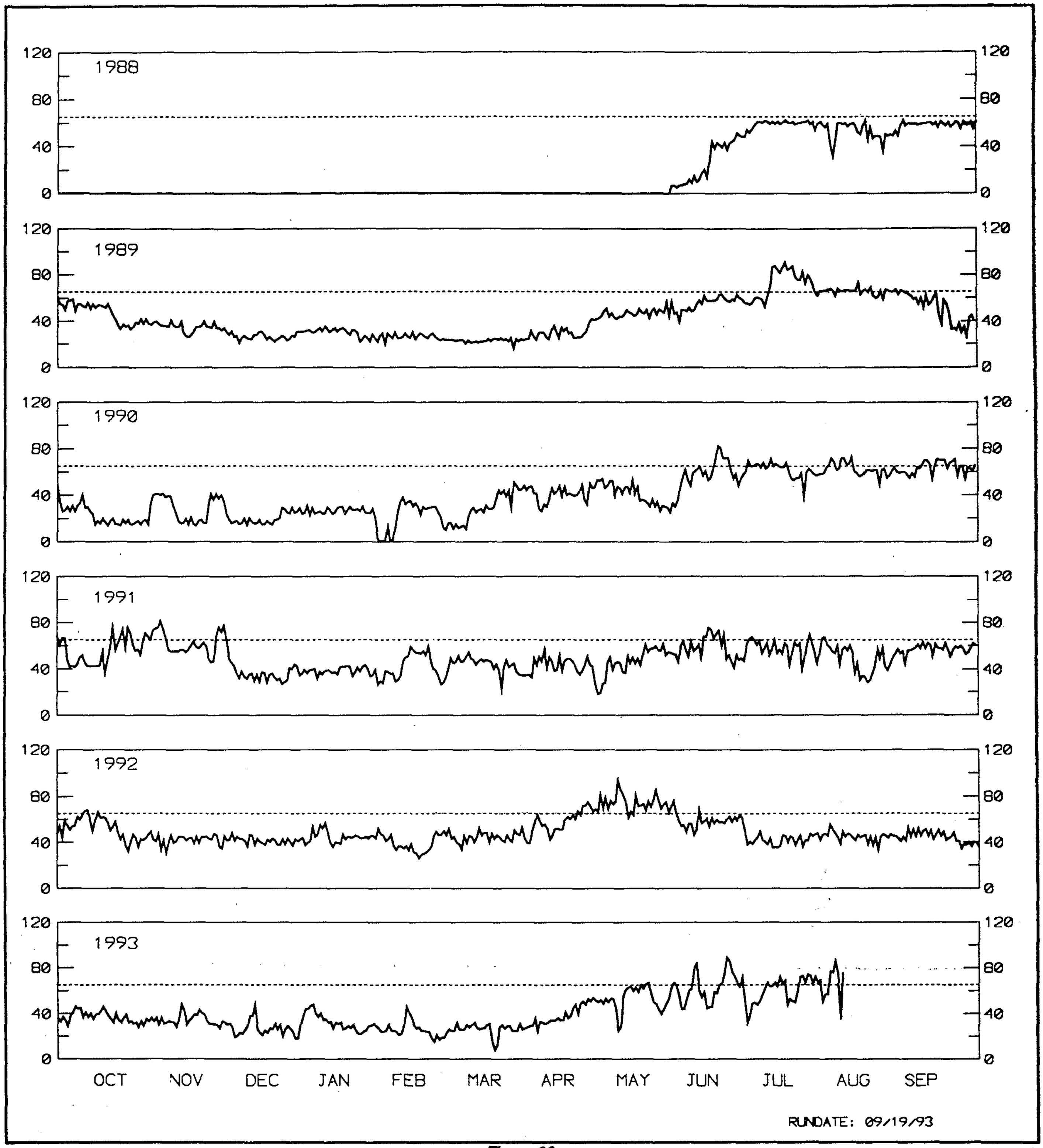


Figure 22
NORTH BAY AQUEDUCT DAILY EXPORTS FOR WATER YEARS 1988 TO 1993
(In Cubic Feet per Second)

The fish screen approach velocity criteria now used by Fish and Game is 0.33 foot per second for continually cleaned screens and 0.0825 fps for non-continuously cleaned screens. Non-continuously cleaned screens require cleaning before through-screen velocities exceed 0.33 fps (DFG 1993).

The effectiveness of this screening criterion to protect delta smelt adults or juveniles from entrainment is not known, because no data are available to define screening criteria for delta smelt. Suitable surrogate species are being evaluated to study for development of interim screening criteria. Delta smelt target size and life stage need to be determined before surrogate species can be selected and the studies conducted. In absence of specific approach velocity criteria for delta smelt, the U.S. Fish and Wildlife Service has used a 0.2-fps criterion established for American shad (USFWS 1993b).

The Department of Fish and Game conducted pre- and post-installation monitoring studies to evaluate impacts of the North Bay Aqueduct on fish. Results of these studies are discussed in Chapter 5.

South Delta Temporary Barriers Project

The existing South Delta Temporary Barriers Project consists of installation and removal of temporary rock barriers at the following locations:

- Middle River near Victoria Canal, about 0.5 mile south of the confluence of Middle River, Trapper Slough, and North Canal.
- Old River near Tracy, about 0.5 mile east of the Delta-Mendota Canal intake.
- Head of Old River near San Joaquin River within 0.1 mile west of the confluence of the two rivers.

The barriers on Middle River and Old River near Tracy are tidal control facilities design[ed to] improve water quality and water levels in southern Delta channels during irrigation season. The barrier at the head of Old River near San Joaquin River is designed to improve conditions in the San Joaquin River during fall Chinook salmon migration.

Although the barriers are temporary structures, some variation of the program will likely be in place through 1995. The original barrier schedule is shown on Figure 23[1]. Variations such as hydrology and endangered species constraints have modified the installation schedule each year the project has been in place. Figure 23 also shows when each barrier has been in place from 1987 to 1993.

Installation of the Old River near San Joaquin River barrier is permitted by the Corps of Engineers from 1968 until 1997. In 1993, the Middle River and the Old River near Tracy barriers were permitted to be in place between June 1 and September 30 on an annual basis until 1995. However, the Department of Water Resources will submit a permit request for the 1994 program to allow installation of all four barriers described in the original program schedule.

If the barriers prove effective in helping San Joaquin River salmon and enhancing southern Delta farmers' ability to manage their water supply, and if they are shown to have minimum negative impacts, the eventual goal will be to install them routinely during spring ar

1 Figure 23 includes a fourth barrier, on Grant Line Canal, which has never been installed and, therefore, is not included in this discussion of existing facilities. DWR will be requesting that the existing permits be amended to allow installation of this barrier in 1994. This request will be addressed in a separate Section 7 consultation

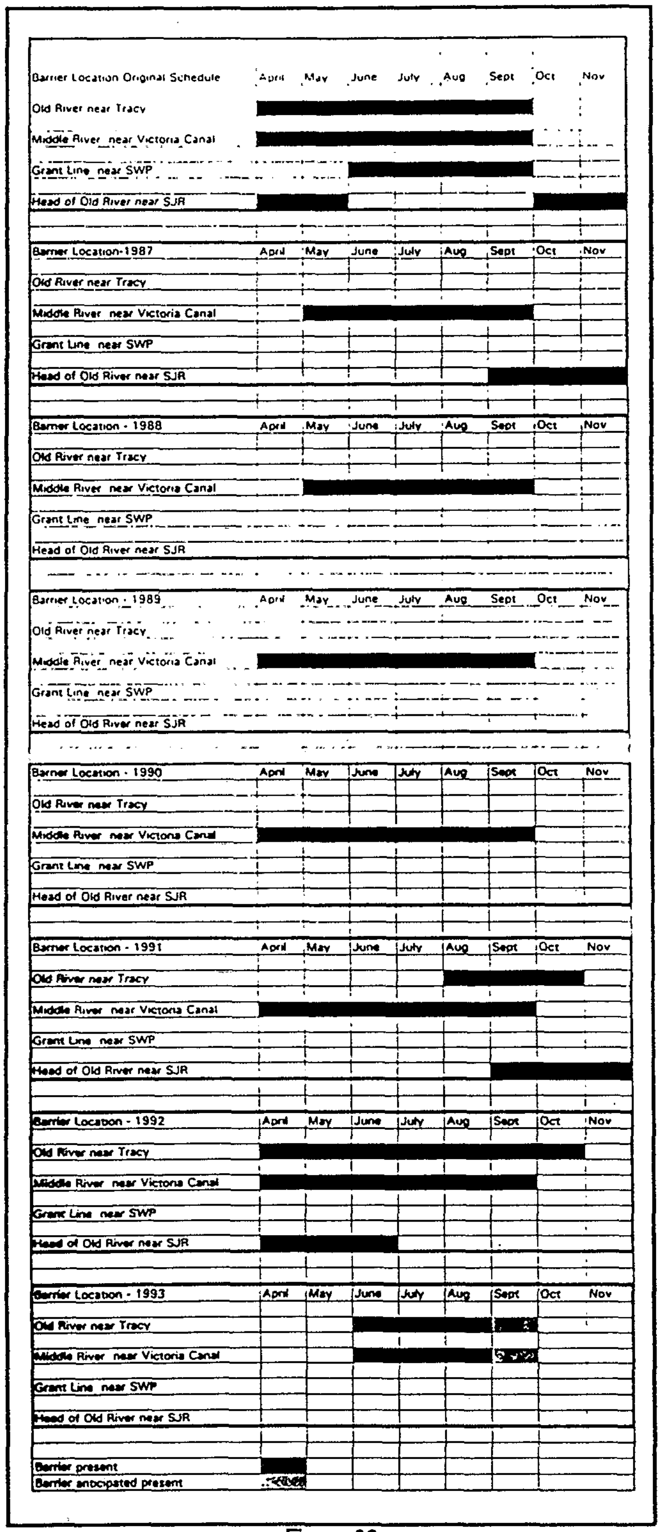


Figure 23
SOUTH DELTA TEMPORARY BARRIER SCHEDULE
1987 TO 1993

summer of many years. Should this occur, design of the barriers will be changed to a permanent structure such as a radial gate.

Following are general descriptions of the three temporary barriers.

Head of Old River near San Joaquin River

The barrier at the head of Old River consists of about 1,800 cubic yards of rock and sand placed across Old River about 0.5 mile west of its confluence with the San Joaquin River. The barrier is about 200 feet long, and 50 feet at its widest point. Side slopes are 1.5 vertical to 1 horizontal. Although the barrier is designed to allow no flow of water over it, it is notched to allow passage of any adult salmon that may be migrating up through Old River to the San Joaquin River. The fall barrier does not have boat portage facilities.

When the barrier period is over, all rock is removed and stockpiled for use during the next installation. The barriers are designed not to impede floodflows, and their installation should not compromise channel integrity.

Old River near Tracy

The proposed temporary tide control facility is in the same location as a temporary barrier installed for 3 months during the drought in 1977 and for about a month in 1991. In 1993 this barrier was installed on June 5. The Department of Water Resources will propose to amend existing permits to allow installation of this barrier as early as April 1, 1994.

About 5,700 cubic yards of rock and sand is placed across Old River near Tracy about 0.5 mile west of the Delta-Mendota Canal intake. The barrier is about 250 feet long and 100 feet at its widest point. Nine 48-inch pipes, each

56 feet long with flapgates, are placed in the barrier to permit flow in one direction. Crest elevation is +2.0 feet, which allows water to flow over the top of the barrier during flood (incoming) tides. During ebb tides, the crest elevation will retain the tidal volume below the +2.0-foot elevation.

The invert of the pipes is at minus 6.0 feet elevation (NGVD). The structure allows tidal flows to enter the channel upstream of the barrier and be retained as the tide ebbs, so agricultural pumps can divert water with less probability of pump damage. Also, the barrier changes circulation flows and may dilute return agricultural drainage to improve the quality of local agricultural diversions.

Boat portage facilities consist of two boat launching ramps and an operated vehicle that tows a universal boat trailer. Boats are loaded onto the trailer and towed up one side of the barrier and lowered to the other side. Six marking buoys are placed about 70 feet apart, three upstream and three downstream, about 200 feet from the centerline of the barrier. Two signs on top of the barrier provide notice to boaters.

When the barrier period is over, all rock is removed and stockpiled for future use. The barriers are designed not to impede flood-flows, and their installation should not compromise channel integrity.

Middle River near Victoria Canal

The Corps of Engineers authorized annual placement of a barrier at this location until 1992. It was installed seasonally from April through September. In 1993, this barrier was incorporated into the South Delta Temporary Barrier Project permit and was installed on June 15.

About 4,800 cubic yards of rock and san placed across Middle River to construct a 27 foot-long berm with a removable center tion. Each end of the barrier, near abutments, contains three 48-inch pipes flapgates. The barrier ends and pipes re in place all year. The tide gates are tied ope when the center section is removed. The ce section is 140 feet long with side slope 2 horizontal to 1 vertical. Crest elevation of t center section is 2 feet lower than the a ment, allowing some flow over the ba even at times other than high tide. The bo portage facility at this site is a gravel ramp can be used to carry or drag a small boat a the barrier.

Friant Division of the Central Valley Project

Friant Dam, the main feature of the F Division, regulates and diverts the flo the upper San Joaquin River. Millerton La behind Friant Dam, has a maximum st capacity of 520,500 acre feet. Average a runoff of the upper San Joaquin River 1.8 million acre-feet. The Bureau of Recl tion has contracts to deliver 2.2 MAF per in the Friant service area, which extends fr Madera County to Kern County. Abo MAF of the total water contracted is Cl about 1.4 MAF is Class II, the difference b reliability of the water supply. In all b driest years, 100 percent of Class I water allocated, whereas the amounts of Cl water that can be regulated for deliver pend on the magnitude and timing of rur and regulation of the runoff by reservoi stream of Friant.

The Madera Canal and Friant-Kern C originate at Friant Dam and convey north and south, respectively, to CVP contr tors within the Friant service area. Capa

Friant-Kern Canal is about 5,300 cfs at the headworks. Capacity of the Madera Canal is about 1,250 cfs at the headworks.

Operation of Friant Dam focuses on regulation and conservation of the water supply to maximize the amount of water available for delivery each year. Because of the relatively small amount of conservation storage available in Millerton Reservoir compared to the typical runoff, emphasis is placed on ensuring sufficient water is available for delivery in a pattern consistent with contractors' water demands.

Southern California Edison Company operates a system of reservoirs, powerplants, and water conduits in the upper San Joaquin basin that significantly regulates inflows to Millerton Lake. An operating contract between the Bureau of Reclamation and Edison is the basis for ongoing coordination of Friant operations with the operation of Edison's system. This agreement, called the Mammoth Pool Contract, was intended to reconcile the rights of the two parties to use San Joaquin River water. The agreement was entered in 1957, before construction of Mammoth Pool reservoir.

Friant Dam is also operated for flood control. Up to 170,000 acre-feet of space may be reserved to regulate inflows. Snowmelt flood control releases may be required in years when the combination of reservoir storage and water deliveries is not sufficient to safely regulate peak snowmelt runoff. To evacuate the flood control pool at Friant, releases may be made into the Madera Canal or Friant-Kern Canal if there is a need for the water; otherwise the water is discharged to the San Joaquin River.

The Bureau of Reclamation releases water into the San Joaquin River to provide a minimum flow of 5 cubic feet per second at Gravelly Ford. This ensures that water will be available for diversion by water right holders on the San Joaquin River between Friant Dam and Gravelly Ford. These releases may vary seasonally from a few cubic feet per second in winter to 100 cfs during peak irrigation season. No other releases are made to the San Joaquin River those required for flood control. Beyond Gravelly Ford, the San Joaquin River has little or no flow until Mendota Pool.

When flood control releases are made from Friant, excess flow in the San Joaquin River may reach Mendota Pool, where it can be diverted for use by the San Joaquin River Exchange Contractors.

Concerns about levee scouring in the San Joaquin River downstream of the bifurcation structure for the Chowchilla Bypass have restricted flow to only about 1,300 cubic feet per second in that section of the river. However, flows in excess of that are rare, not well forecastable, and of short duration.

Excess flows entering the Chowchilla Bypass are the only other means by which releases from Friant Dam can reach the Delta. Such a condition last occurred in March through June 1993.

New Melones Dam and Reservoir

New Melones Dam is on the Stanislaus River, about 35 miles northeast of Modesto. It is an earth and rockfill structure 625 feet high with a capacity of 2.4 million acre-feet, 450,000 of which is reserved for flood control. The dam was built by the U.S. Army Corps of Engineers and transferred, when completed in 1979, to the U.S. Bureau of Reclamation for operation and maintenance as the key feature of the East-Side Division of the Central Valley Project.

Project purposes are flood control, power generation, irrigation supply, water quality control, fishery enhancement, and recreation. Operations of New Melones and Tulloch reservoirs are coordinated, per agreement with

Tri-Dam Project, with Tulloch Reservoir operated as an afterbay. Goodwin Dam, just downstream of Tulloch, acts as a diversion structure to provide irrigation water to Oakdale Irrigation District and South San Joaquin Irrigation District to meet their water rights under an agreement with the Bureau of Reclamation.

Under terms of State Water Resources Control Board Water Right Decision 1422, water quality objectives for New Melones are:

- Dissolved oxygen of 7.0 mg/L or higher at all times at the Stanislaus River at Ripon.
- Total dissolved solids of 500 mg/L (monthly average) at the San Joaquin River near Vernalis.

Decision 1422 calls for up to 98,000 acre-feet to be released for maintenance of fish and wildlife. The fishery enhancement is mainly flow augmentation, including spring pulse flows in April and May, fall attraction flows in October, and maintenance of minimum flows in other months. The spring pulse flows have been intended in the past for assisting outmigrating salmon smolts, but they also contribute to San Joaquin River pulse flows for delta smelt and other species. The fall attraction flows also tend to increase the dissolved level at Stockton, but they are relatively inefficient because much of the flow released to the San Joaquin River is lost to Old River and, therefore, does not support the flow past Stockton.

In addition, special consideration is given each fall to releases required to meet the 56°F target on the lower Stanislaus River.

Coordinated Operation Agreement

The Central Valley Project and State Water Project use the Sacramento River and the Delta as common conveyance facilities. Reservoir releases and Delta exports must be coordinated to ensure that each of the projects retains its portion of the shared water and bears its share of the obligation to protect beneficial uses.

The Coordinated Operation Agreement between the U.S. Bureau of Reclamation and the California Department of Water Resources became effective in November 1986. The agreement defines the rights and responsibilities of the CVP and SWP regarding Sacramento Valley and Delta water needs and provides a means to measure and account for those responsibilities. The Coordinated Operation Agreement includes a provision for its periodic review.

Obligations for In-Basin Uses

In-basin uses are defined in the Coordinated Operation Agreement as "legal uses of water in the Sacramento Basin including the water required under the Delta standards found in SWRCB Decision 1485 (D-1485)". The CVP and SWP are obligated to ensure that water is available for these specific uses, but the degree of obligation depends on several factors and changes throughout the year.

Balanced water conditions are defined in the Coordinated Operation Agreement as periods when the two projects agree that releases from upstream reservoirs plus unregulated flows are about equal to the water supply needed to meet Sacramento Valley in-basin uses plus exports. ***Excess water conditions*** are periods when the CVP and SWP agree that releases from upstream reservoirs plus unregulated flow exceed Sacramento Valley in-basin uses plus exports.

During excess water conditions, sufficient water is available to meet all demands and requirements; under these conditions, the CVP and SWP have agreed in the Coordinated Operation Agreement to store and export as much water as possible.

During balanced water conditions, the two projects share in meeting in-basin uses. Balanced water conditions are further defined according to whether water from upstream storage is required to meet Sacramento Valley in-basin use or if unstored water is available for export.

When water must be withdrawn from storage to meet Sacramento Valley in-basin uses, 75 percent of the responsibility for withdrawing water is borne by the CVP and 25 percent is borne by the SWP. When unstored water is available for export (*ie,* balanced water conditions and exports exceed withdrawals), the sum of CVP stored water, SWP stored water, and the unstored water for export is allocated 55 percent to the CVP and 45 percent to the SWP.

Accounting and Coordination of CVP and SWP Operations

With daily coordination, the Bureau of Reclamation and Department of Water Resources determine the target Delta outflow for water quality, reservoir releases to meet in-basin needs, and schedules to use each project's facilities for pumping and conveyance.

During balanced water conditions, a daily accounting is maintained according to the sharing formulas agreed to in the Coordinated Operation Agreement to show CVP and SWP accumulated obligations. This allows flexibility in operations by allowing either party's share to vary on a daily basis, thereby avoiding the need to make daily changes in reservoir releases that originate several days' travel time from the Delta. During balanced conditions, adjustments can also be made afterward rather than by predicting the variables of reservoir inflow, storage withdrawals, and in-basin uses on a daily basis.

Releases are one means of adjusting to changing in-basin conditions. During balanced water conditions, Delta outflow can be increased almost immediately by reducing project exports.

Decision 1485 standards require that the CVP and SWP each limit pumping to an average of 3,000 cubic feet per second during May and June. This constraint is particularly strict for operating the CVP, because its annual exports are limited by the capacity of Tracy Pumping Plant and Delta-Mendota Canal. The Coordinated Operation Agreement and Decision 1485 allow as much as 195,000 acre-feet to be pumped at Banks Pumping Plant to replace this lost export. If this water is pumped during balanced water conditions, the CVP is responsible for supplying the water at Banks Pumping Plant.

When real-time operations dictate CVP and SWP actions, an accounting procedure tracks the water obligations of the two projects. When the difference between obligations is sufficient, adjustments may be made in reservoir releases to allow the project that has carried more than its obligation to recoup the water while the other project compensates for its deficient contribution.

During any given year, water conditions can go in and out of balance. Account balances continue from one balanced water condition through an excess water condition and into the next balanced water condition. If, however, the project with a positive balance (*ie,* the party that has provided more than its accumulated share of water) enters into flood control operations, the accounting is reset to zero.

Limitations of the Present Coordinated Operation Agreement

Current Endangered Species Act operational restrictions in the Delta are not addressed by the Coordinated Operation Agreement. The two ESA restrictions that have affected coordinated operations between the CVP and SWP are the QWEST standard and the take limitations at the export pumping facilities.

The QWEST standard is a CVP/SWP operational limitation implemented in the long-term winter-run Chinook salmon biological opinion and the 1993 delta smelt biological opinion. Technically QWEST is an index of reverse flow in the lower San Joaquin River. QWEST regulates the amount of CVP/SWP export capability based on the Delta hydraulic conditions of the San Joaquin River, eastside streams (Mokelumne, Cosumnes, and Calaveras rivers), Delta precipitation and estimated local consumptive use, Sacramento River flow, and Delta Cross Channel operations. QWEST conditions can be operationally influenced through three controllable mechanisms: Delta Cross Channel operations, Sacramento River flow, and total CVP/SWP export pumping.

QWEST is not a constraint that was considered or even contemplated in negotiations and studies that led to the Coordinated Operation Agreement. The Decision 1485 standards contained in the Agreement are water quality and Delta outflow standards, not export restrictions based on Delta hydraulic conditions. Imposition of QWEST on combined project operations has created a number of key coordination issues:

- The definition of balanced water conditions is not appropriate when QWEST is the controlling Delta criterion.
- The priority of CVP or SWP export pumping during periods when QWEST is the controlling constraint is not defined.
- The responsibility for satisfying QWEST with releases from upstream reservoirs when both projects continue exports is not defined.
- How the benefits of Delta Cross Channel gate operations are now to be applied to CVP or SWP export capability has not been determined.

The long-term winter-run Chinook salmon biological opinion and the 1993 delta smelt biological opinion both contain provisions for incidental take limitations at the combined CVP/SWP export facilities. Neither addresses operation of the individual export facilities; rather they require coordinated operation of the CVP and SWP to address endangered species take. The present Coordinated Operation Agreement has no provision to address individual project responsibility for endangered species take.

As a result of QWEST and take limitations in the Delta, the Coordinated Operation Agreement relationship between the CVP and SWP has been clouded to the point that individual project operations cannot be forecast satisfactorily on a long-term basis. The operational relationships between the water projects are complex and cannot be fully addressed until all operational and regulatory issues in the Delta are firm. Operations required by the Endangered Species Act affect the Coordinated Operation Agreement and, in turn, the COA affects ESA operations.

In 1993, the CVP and SWP were not operated in strict accordance with the Coordinated Operation Agreement concerning sharing the available water supply. By mutual agreement, in light of Endangered Species Act requirements, the Bureau of Reclamation and Department of Water Resources have apportioned the water supply and responsibility for Delta standards between the projects. Operations in 1993 were complicated by problems meeting the QWEST standard, the take limits for winter-run Chinook salmon and delta smelt, and the CVPIA operational prescriptions. A wet winter in 1993 provided the flexibility for the projects to operate in this manner without severe COA problems.

Regulatory Requirements for Delta Water Quality, Flow, and Operations

Delta water quality standards and the beneficial uses they protect are defined in Decision 1485, which also addresses minimum Delta flow requirements.

Beneficial uses protected by Decision 1485 include agriculture, M&I, and fish and wildlife. Delta standards apply throughout the year but become more critical whenever balanced water conditions exist in the Delta, typically from April through November but varying depending on hydrologic and storage conditions.

In addition to Decision 1485 water quality standards, CVP and SWP operational decisions are based on the current water supply and hydrologic conditions and impacts and benefits to fisheries, recreation, and power. The uncontrollable variables of tides, winds, barometric pressure, river depletions, and agricultural drainage affect the ability of the CVP and SWP to comply with the water quality standards.

Operational actions initiated to maintain Delta water quality are based on past experience and empirical studies, which are used as guides for determining initial responses to Delta conditions. Operations are changed according to varying Delta conditions, and they provide a reasonable level of protection against noncompliance with the standards.

Depending on the water year classification[1], complying with the Decision 1485 Delta water quality standards and fishery flows requires from 3.0 to 5.5 million acre-feet annually, as measured by the Delta Outflow Index.

Because of the hydraulic characteristics of the Delta, some standards are managed more efficiently through export curtailments; others are managed more efficiently through flow increases. For example, the Contra Costa and Jersey Point standards are managed more efficiently by export curtailments. While complying with these standards, CVP and SWP operators also target a Delta Outflow Index and salinity levels in the western Delta. These levels are expected to provide a reasonable margin of error against noncompliance with Decision 1485 should adverse or unforeseen conditions arise.

In typical or full delivery years, a curtailment at Tracy Pumping Plant will likely adversely affect CVP water supply availability south of the Delta. During such times, the SWP usually makes short-term curtailments, because its ability to recover from such curtailments is significantly greater than that of the CVP.

In contrast, the Decision 1485 Emmaton water quality standard is more efficiently managed by flow increases. In most instances, salinity levels at Emmaton react proportionately to increases in flow in the Sacramento River along Sherman Island, where the Emmaton recorder is located. Closing the Delta Cross Channel gates increases flow in the Sacramento River and reduces flows in the lower San Joaquin River. Without additional outflow water, reverse flows on the San Joaquin side of the Delta result in increased salinity in the central and southern Delta. For this reason, the Delta Cross Channel gates can usually be closed for only a day or two before deteriorating water quality on the San Joaquin River side of the Delta requires that the Cross Channel gates be reopened.

1 Decision 1485 defines water year classifications.

Another way to increase flows on the Sacramento River is to increase the releases from the CVP and the SWP. The approximate lag times for releases from the two projects to reach the Delta are shown below.

Dam	River	Lag Time
Nimbus (Folsom)	American	1 day
Oroville	Feather	3 days
Keswick (Shasta)	Sacramento	5 days

In a typical water year, releases may be increased simultaneously on all three rivers. The largest initial release increase would be on the American River. Then, as increased releases in the Feather and Sacramento rivers reach the Delta, the American River release would be decreased accordingly.

Winter-Run Chinook Salmon Biological Opinion

On February 12, 1993, the National Marine Fisheries Service released the *Biological Opinion for the Operation of the Federal Central Valley Project and the California State Water Project,* concerning Sacramento River winter-run Chinook salmon. The biological opinion contains "reasonable and prudent alternatives" to be implemented by the Bureau of Reclamation, Department of Water Resources, and other agencies to avoid jeopardizing Sacramento River winter-run Chinook salmon in the long-term operation of the water projects. It also contains an incidental take statement with terms and conditions that must be complied with to monitor and/or minimize the incidental take of winter-run Chinook salmon. The actions identified in the reasonable and prudent alternative and in the reasonable and prudent measures in the incidental take statement are discussed below.

Reasonable and Prudent Alternatives

Actions 1 through 5 concern the Shasta/Trinity and Sacramento River Divisions of the Central Valley Project. Action 6 pertains to gate operation at Red Bluff Diversion Dam. These actions will not directly affect delta smelt, so they are not discussed here.

Actions 7 through 13, concerning the Delta Division of the Central Valley Project and the State Water Project, are discussed below.

7. The Bureau must maintain the Delta Cross Channel Gates in the closed position from February 1 through April 30 to reduce the diversion of juvenile winter-run Chinook salmon emigrants into the Delta.

The purpose of this action is to improve overall survival of the winter-run Chinook salmon emigrant population by reducing the number of fish exposed to adverse conditions in the central Delta. Sampling in the Delta indicates February through April is the primary period of winter-run Chinook salmon emigration through the Delta. This action will reduce flow in the lower Mokelumne River and lower San Joaquin River and, therefore, QWEST.

8. Based on the observations of a real-time monitoring program in the lower Sacramento River, the Bureau must operate the gates of the Delta Cross Channel during the period of October 1 through January 31 to minimize the diversion of juvenile winter-run Chinook salmon into the central Delta. The Bureau must develop the real-time monitoring program and fisheries criteria for gate closures and openings in coordination with the National Marine Fisheries Service, U.S. Fish and Wildlife Service, California Department of Fish and Game, and the California Department of Water Resources by August 1, 1993. The Bureau must ensure that continuous real-time monitoring is conducted between October 1 and January 31 of each year commencing in 1993.

Monitoring for winter-run Chinook salmon will not directly aid delta smelt. To the extent that such a monitoring program will indirectly collect information about the presence and distribution of delta smelt, it will contribute to the body of knowledge on delta smelt.

> 9. Based on 14-day running average of QWEST in cfs, the Bureau and the California Department of Water Resources must operate the Delta water export facilities to achieve no reverse flow in the western Delta from February 1 through April 30. The 7-day running average, if negative, must be within 1,000 cfs of the applicable 14-day running average during this period.

Eliminating reverse flows in the western Delta from February through April may reduce losses of winter-run salmon juveniles in the Delta. As discussed in Chapter 5, the influence of reverse flows on survival of delta smelt and other species is inconclusive.

> 10. Based on the 14-day running average of QWEST in cfs, the Bureau and the California Department of Water Resources must operate the Delta export water facilities to achieve flow in the western Delta greater than negative 2,000 cfs from November 1 through January 31. The 7-day running average, if negative, must be within 1,000 cfs of the applicable 14-day running average during this period.

Maintaining lower reverse flows in the lower San Joaquin River may reduce losses of juvenile winter-run Chinook salmon pre-smolts from October through January. The effect of this standard on delta smelt, although not well understood, is discussed in Chapter 5.

> 11. Continue and expand monitoring of winter-run Chinook salmon in the lower Sacramento River and Sacramento-San Joaquin Delta to establish their presence, residence time, and serve as a basis for the real-time management of Delta Cross Channel gate operation.

Monitoring for winter-run Chinook salmon will not directly aid delta smelt. To the extent the monitoring will indirectly collect information about the presence and distribution of delta smelt, it will contribute to the body of knowledge on delta smelt.

> 12. The Bureau in coordination with the Contra Costa Water District must develop and implement a program to monitor entrainment loss of winter-run Chinook salmon juveniles at the Rock Slough intake of the Contra Costa Canal.

A program to monitor winter-run Chinook salmon at the Contra Costa Canal will begin when the monitoring plan has been reviewed and approved by the National Marine Fisheries Service. Monitoring for delta smelt is required by a biological opinion for the Los Vaqueros Project. A monitoring plan must be submitted to the U.S. Fish and Wildlife Service by early December 1993, and monitoring must begin within 4 months after approval of the plan.

> 13. The Bureau and Department of Water Resources in cooperation with California Department of Water Resources [actually meant DFG] must monitor the extent of incidental take associated with operation of the Tracy and Byron [Banks] pumping facilities.

The Bureau of Reclamation and Department of Water Resources have instituted measures and procedures to better monitor for winter-run Chinook salmon and delta smelt at CVP and SWP fish protective facilities.

Reasonable and Prudent Measures in the Incidental Take Statement

Measures 1 through 8 concern operation of the Shasta, Trinity, and Sacramento River division. These actions will not directly affect delta smelt.

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Measures 9 through 13 concern Delta operations of the Central Valley Project and the State Water Project.

9. The DWR and the Bureau are authorized to take up to 1 percent of the estimated number of out migrating smolt winter-run incidental to the operation of the Delta pumping facilities at Byron and Tracy.

In 1993, these incidental take limitations significantly reduced the export capability of the water projects, particularly the SWP. (In 1993, exports were reduced by 525,000 acre-feet due to winter-run smolt take at the state facilities.) This will reduce incidental take of delta smelt, particularly in winter and summer. The potential effect of export reductions on delta smelt is discussed in Chapter 5.

10. The California Department of Water Resources in coordination [with] the Bureau must develop and implement a program of Chinook salmon investigations at the Suisun Marsh Salinity Control Structure and within Montezuma Slough.

The Department of Fish and Game has continued a sampling program to monitor and assess the effects of Montezuma Slough gate operations on juvenile and adult salmon migration and predation levels near the gates. This program was a permit requirement for construction and operation of the salinity control gates under the Suisun Marsh Plan of Protection, which is coordinated between the Department of Water Resources and the Bureau of Reclamation.

11. The Bureau and California Department of Water Resources must ensure that the fish collection facilities are fully staffed for monitoring incidental take and the screens fully operated whenever Tracy and Banks pumping plants are in operation from October 1 through May 31.

The CVP and SWP fish collection facilities are fully staffed, and screens will be operated in accordance with the agreed salmon criteria. Salvage procedures to be used during the 1993-94 season are being developed by the Interagency Program[1] work group on winter-run loss, salvage, and monitoring. These procedures will be in place by October 1, 1993. Operation of the fish facilities is critical for compliance with take limitations for winter-run Chinook salmon and delta smelt.

12. The Bureau in coordination with the California Department of Water Resources must develop and implement a demonstration screening program designed to promote the advancement of state-of-the-art positive-barrier screening technology at small unscreened diversions along the Sacramento River and within Delta waterways.

The Bureau of Reclamation sponsored a screening workshop in spring 1993. A fish screen demonstration program has been implemented, and the Department of Water Resources is testing a rotating drum screen for Delta agricultural diversions as part of the Interagency Program agricultural diversion studies.

13. The Bureau in coordination with the California Department of Water Resources must submit daily, weekly, and annual reports to the National Marine Fisheries Service regarding operation of project facilities, temperature and hydrological conditions, and the results of monitoring programs.

Reporting procedures are in place and data are routinely transmitted to the National Marine Fisheries Service, California Department of Fish

1 The Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary was formed in 1970. In 1993, member agencies are the California Department of Water Resources, U.S. Bureau of Reclamation, California Department of Fish and Game, U.S. Fish and Wildlife Service, U.S. Geological Survey, State Water Resources Control Board, U.S. Army Corps of Engineers, and U.S. Environmental Protection Agency.

and Game, and U.S. Fish and Wildlife Service, as appropriate.

14. The Bureau must establish a working operations and management group that includes the National Marine Fisheries Service to address the implementation of the reasonable and prudent alternative.

The operations and management group was convened in June 1993 and will continue to meet as necessary to consider issues involving implementation of the reasonable and prudent alternative.

15. The Bureau, in coordination with Water Resources, must develop new sampling and analytical methodologies for estimating winter-run Chinook salmon salvage and loss numbers at the fish collection facilities that is acceptable to the National Marine Fisheries Service.

The Bureau of Reclamation and Department of Water Resources have adopted procedures for estimating winter-run salvage and losses based on recommendations by the loss, salvage, and monitoring work group. The procedures have been reviewed by statisticians for the Department of Fish and Game. Sampling and analysis may be limited by the scarcity of winter-run Chinook, by uncertainties inherent in their identification, and by factors used to expand observations to estimated losses. Experience and further experimentation may help resolve some of the uncertainty.

16. The Bureau must develop, in consultation with the National Marine Fisheries Service, a winter-run Chinook population model that can be used to evaluate the long-term effects of CVP operations plans on the winter-run Chinook salmon survival and recovery.

Several salmon population models exist, but none specifically for evaluatinng the effects of CVP/SWP operations on winter-run Chinook.

Delta Smelt Biological Opinion

On May 26, 1993, the U.S. Fish and Wildlife Service released a biological opinion, *Formal Consultation on Central Valley Project Operations Criteria and Plan for 1993: Effects on Delta Smelt.* This opinion was the result of an April 1, 1993, request by the Bureau of Reclamation for a formal consultation pursuant to Section 7 of the Endangered Species Act.

This biological opinion addresses effects of proposed operations and planning of the Central Valley Project and State Water Project beginning February 15, 1993, and ending February 15, 1994, which include modifications on delta smelt that will result from the long-term winter-run biological opinion.

Reasonable and Prudent Measures

The biological opinion established the following reasonable and prudent measures to minimize the impact of the incidental take of delta smelt.

1. Improve salvage operations at Tracy and Skinner Fish Protection Facilities during the spawning interval.

2. Improve estimates of larval and juvenile delta smelt take at the Tracy and Skinner Fish Protection Facilities during the spawning interval.

Operations of Tracy and Skinner Fish Protection facilities have been addressed through ongoing consultations with the Department of Fish and Game and National Marine Fisheries Service. Procedures to improve estimates of delta smelt take have been implemented.

3. Decrease pumping at the Barker Slough intake on the North Bay Aqueduct during the spawning interval.

The Department of Water Resources and Bureau of Reclamation are evaluating the feasibility of developing water storage and/or water exchanges to meet part of the water supply demands of the North Bay Aqueduct when delta smelt are present in Barker Slough. This would allow some pumping to be shifted from periods when smelt are present to when they are not. Other options include real-time monitoring for smelt in the slough to allow regulation of pumping rates.

> 4. Decrease pumping at the Federal Tracy and State Banks pumping plants during the interval when large numbers of larval and juvenile delta smelt appear at the Federal and State fish screens.

Operations of the Tracy and Banks pumping plants include reductions in pumping levels in response to increased delta smelt take.

> 5. Set QWEST requirements that reduce delta smelt juvenile and adult losses in August and, January and February, respectively.

QWEST requirements were set by Condition 5 (below) and have been met to date.

Terms and Conditions

The biological opinion also imposed the following terms and conditions, which implement the reasonable and prudent measures described above.

> 1. At the Tracy and Skinner Fish Protection Facilities, between the issuance of this opinion and July 31, fish shall not be held more than 8 hours before being deposited at a dump site. One additional dump site shall be added for each facility to minimize accumulation of predators at each site. A plan shall be submitted to the Service with 30 days of finalization of this opinion and the new dump sites shall be in place by January 1, 1994.
> (The U.S. Fish and Wildlife Service subsequently clarified this term, indicating that the fish were to be held no more than 8 hours before beginning transport to release sites.)

The Bureau of Reclamation has added a dump site, and the Department of Water Resources is proceeding to add a site. The Interagency Program work group convened to help implement the measures has agreed to investigate the effect of holding time on smelt survival. The 8-hour limit is being observed.

> 2. Adequately trained personnel shall be in place at both the Tracy and Skinner Fish Protection Facilities to make counts on delta smelt larvae and juveniles during the spawning period of February 1 through July 31. Estimates of larvae and juveniles salvaged at the fish facilities and larvae and juveniles entrained by the Tracy and Banks Pumping Plants shall be transmitted to the Services' Sacramento Field Office three times a week beginning immediately on issuance of this opinion.

Federal and State operating personnel have received training on fish identification. A reporting procedure has been implemented to communicate daily salvage at the state and federal facilities.

> 3. The Barker Slough intake on the North Bay Aqueduct shall have pumping limited to a 14-day average rate of 65 cfs during the spawning interval implemented immediately on the issuance of this opinion through July 31.

Diversions at Barker Slough were curtail[ed] during 1993 to comply with this provision. Operations maintained a 14-day avera[ge] pumping rate of 65 cubic feet per second [or] less through July 31, 1993, to meet require[-] ments of the delta smelt biological opinion.

> 4. The Tracy and Banks Pumping Plant shall be limited to a 14-day combined average ra[te] of 4,000 cfs during May 1993, and 5,000 c[fs] during June 1993. This limitation on pumping shall be increased an additional 1,000 cfs [in] May and June, and re-evaluated daily for [the] need for additional pumping limitations if th[e] daily estimated combined delta smelt salv[age]

> at the Federal and State fish protection facilities is 400 delta smelt larvae or juveniles, or more. The limitations shall be extended to include a 3,000 cfs 14-day combined export rate or less in July, if the daily estimated combined delta smelt salvage at the Federal and State fish protection facilities is 400 delta smelt larvae or juveniles, or more.

Operations during the first weeks of June 1993 showed that this condition was unworkable. On June 25, the Bureau of Reclamation proposed the following condition to replace condition 4; the U.S. Fish and Wildlife Service approved this new condition on June 30.

> 4. The Tracy and Banks Pumping Plant shall be operated during May, June and July to minimize the taking of delta smelt at 14-day combined average rate of 4,000 cfs during May, 5,000 cfs during June, and 9,200 cfs (including Contra Costa pumping) during July. When the 14-day running average of estimated combined delta smelt salvage at the Federal and State fish protection facilities equals or exceeds 400 delta smelt (larvae greater than 21 mm and juveniles), the combined rate of pumping shall be immediately reduced in order to restore the 14-day running average delta smelt salvage limit. On the next working day, Reclamation will report to Fish and Wildlife Service the magnitude of the exceedence of the limit on combined salvage, a description of measures being taken by Reclamation and DWR to restore the 14-day running average salvage to an amount less than 400, and an estimate of the duration of the period of exceedence.

This condition was met during the specified period.

> 5. Based on the 14-day running average of QWEST, the flow in the western Delta shall exceed negative 2,000 cfs from August 1-31, 1993, and shall exceed negative 1,000 cfs from January 1 through February 15, 1994.

This term has been met through August 31, 1993.

Chapter 5

FACTORS THAT MAY INFLUENCE DELTA SMELT ABUNDANCE AND DISTRIBUTION

A number of factors may influence size and distribution of the delta smelt population. These include Delta outflow and the location of the entrapment zone, entrainment into a variety of Delta diversions, reverse flow, predation and competition with native and introduced species, food abundance, water quality, contaminants, disease and parasites, interbreeding with closely-related species, and spawning stock size.Although many of these factors are interrelated, they are discussed individually in this chapter.

Delta Outflow and the Entrapment Zone

Delta outflow is the amount of fresh water that flows past Chipps Island into Suisun Bay. Because it is not yet possible to measure directly, an index of Delta outflow is calculated using the inflow to the Delta; State Water Project, Central Valley Project, and Contra Costa Canal exports from the Delta; and estimated depletions of channel water within the Delta. Total Delta outflow levels are shown in Figure 24.

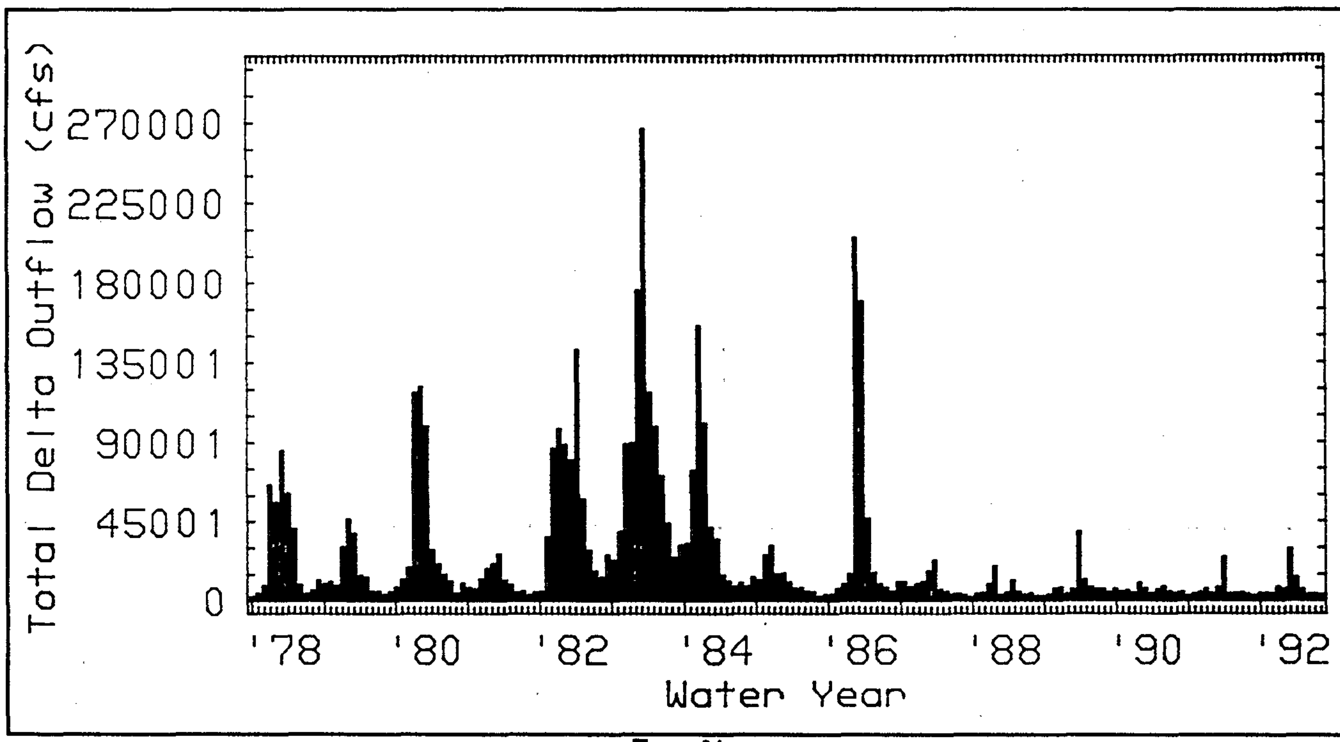

Figure 24
AVERAGE MONTHLY TOTAL DELTA OUTFLOW, WATER YEARS 1978 TO 1992
From the DAYFLOW Database

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Outflow (and diversions) may affect the speed and direction of fish movement in and through the Delta. A reduction in transport time may adversely affect delta smelt, which spawn upstream and depend on currents to distribute their larvae throughout the nursery area. There is evidence that freshwater outflow may also influence the abundance and distribution of many other species. Outflow acts as a hydraulic barrier to reduce movement of salt upstream from the ocean. It also determines the location of the entrapment zone. These factors are discussed below, beginning with a discussion of the influence of hydrology on Delta outflow.

Effect of Hydrology on Outflow

Delta outflow is influenced by both human activities and natural occurrences. Human influences include Delta diversions, upstream reservoir regulation of water throughout the Central Valley, and upstream diversions and return flows. The major natural factors are Central Valley precipitation patterns and corresponding runoff.

The Sacramento River Index is a measure of unimpaired runoff for the Sacramento Valley. Figure 25 shows the Sacramento River Index for 1967 through 1992 and the long-term average for 1905 through 1992. The figure reflects the variability of Central Valley hydrology over the last 26 years.

Figure 26 shows that recent years have deviated significantly from the long-term mean. The late 1960s and early 1970s were somewhat wetter than normal, followed by a sharp decline during the 1976/1977 drought. The 1980s and early 1990s show a high deviation from the long-term average, with exceptionally wet years (1982-1984) and extreme drought (1987-1992).

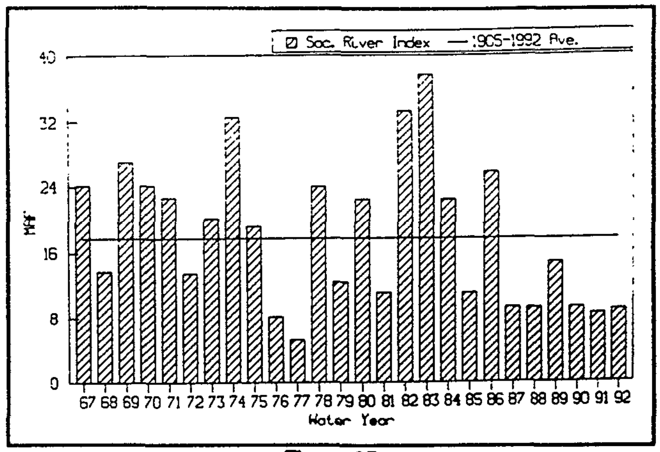

Figure 25
SACRAMENTO RIVER INDEX
UNIMPAIRED HYDROLOGY, 1967 TO 1992

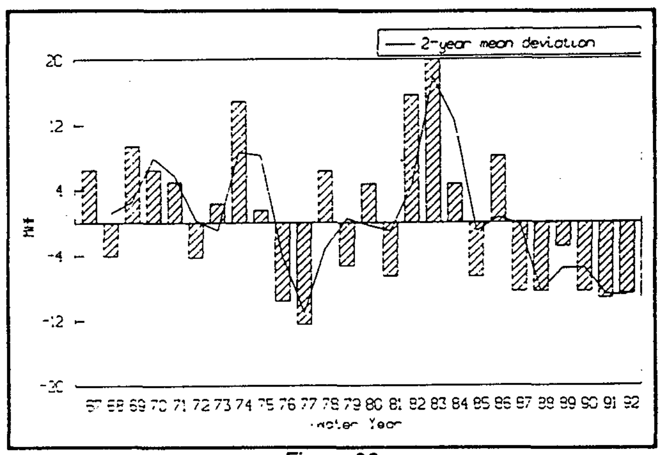

Figure 26
SACRAMENTO RIVER INDEX
DEVIATION FROM LONG-TERM AVERAGE, 1967 TO 1992

Hydrologic variability is an uncontrollable part of any natural or regulated ecosystem. The 1980s and early 1990s contain one of the wettest and one of the driest periods recorded in the Central Valley. The uncontrollable aspect of Delta hydrology must be recognized as a factor that determines and affects outflow and, therefore, could affect the abundance and distribution of delta smelt.

Delta Outflow

Decreases in outflow during drought years have been reported to affect the abundance of a number of biological resources of the estuary (Armor 1992).

Moyle and Herbold (1989) suggest that delta smelt benefit from moderately high flows, which place the primary nursery area in Suisun Bay. However, Stevens and Miller (1983) and Moyle *et al* (1992) did not find any statistical relationship between delta smelt abundance indices and outflow. This indicates that if outflow does affect smelt abundance, the influence may be small relative to other factors in some or all years.

Delta outflow does appear to have a strong impact on geographical distribution of delta smelt. Stevens *et al* (1990) showed that significantly more delta smelt were found west of the Delta when outflows were high. As shown in Figure 27, the tow-net index for the first and second tow-net surveys of each year[1] (survey=1, survey=2 on the figure) in the Suisun Bay region increases directly with outflow.

A similar trend is evident for the fall midwater trawl survey for September through December[1] (Figure 28). Sweetnam and Stevens (1993) hypothesized that delta smelt survival may be enhanced in Suisun Bay, based on the observation that abundance indices for the estuary have often been high when large numbers of delta smelt were collected in Suisun Bay. Nonetheless, no statistical relationship has been found between outflow and abundance.

Entrapment Zone

The entrapment zone is a transient region of the estuary where fresh water and salt water interact to concentrate the level of suspended particulate matter. It is formed as fresh water flows downstream over the more dense, landward-flowing salt water, creating a circulation pattern that concentrates particles such as sediment and plankton. A definition of either 2 microSiemens per centimeter surface specific conductance or 2 parts per thousand isohaline position (X2) is frequently used as an index of the upstream end of the entrapment zone (Arthur and Ball 1978, Kimmerer 1992a).

Entrapment zone location is regulated by the interaction of tides, Delta outflow, and the complex bathymetry of the estuary, as well as mixing by wind in shallow waters (Peterson *et al* 1975, Arthur and Ball 1978). Since 1972 it has generally been between Honker Bay and Sherman Island, but in extreme water years it has

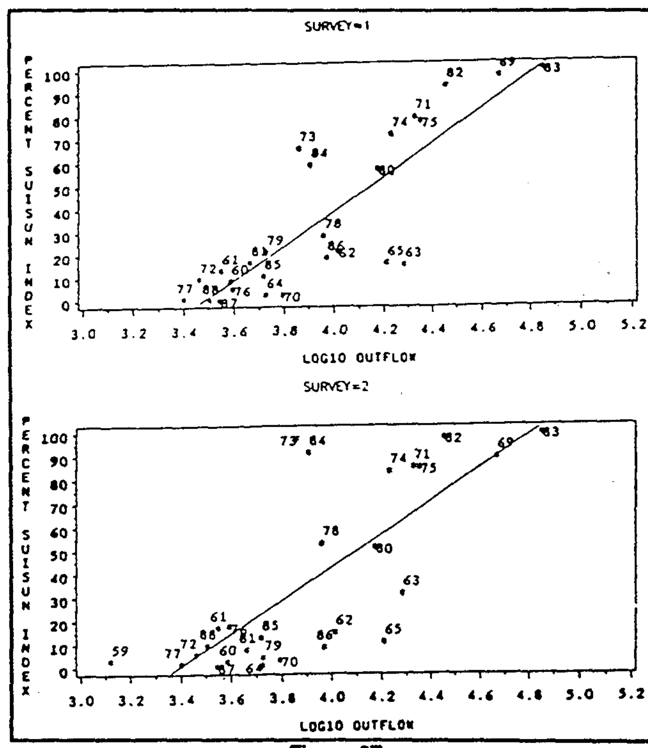

Figure 27
RELATIONSHIP BETWEEN THE PORTION OF DELTA SMELT POPULATION WEST OF THE DELTA AND LOG DELTA OUTFLOW DURING THE SURVEY MONTH FOR SUMMER TOW-NET SURVEY, 1959 TO 1988
For arcsine transformed percentages, $r^2 = 0.74$ for survey 1 and $r^2 = 0.55$ for survey 2.
Source: Sweetnam and Stevens 1993.

1 Results from 1989 to 1993 have not yet been analyzed.

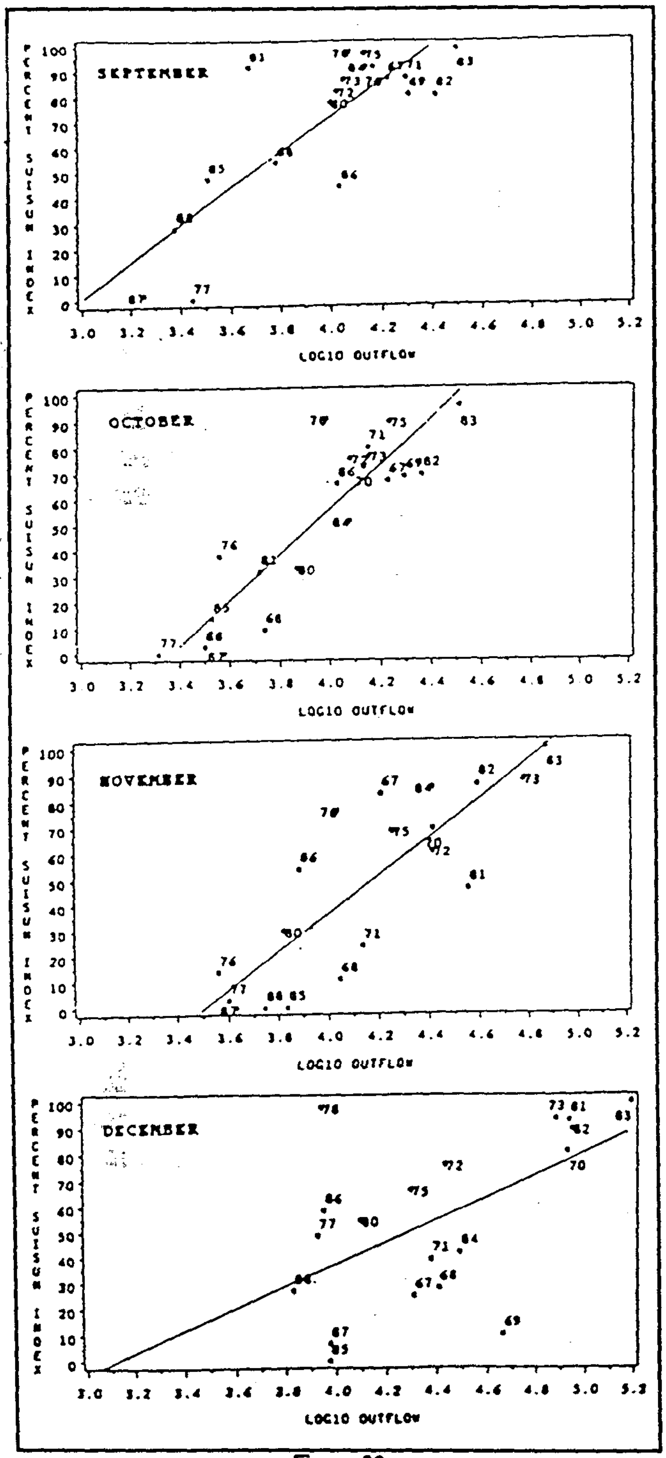

Figure 28
RELATIONSHIP BETWEEN THE PORTION OF DELTA SMELT POPULATION WEST OF THE DELTA AND LOG DELTA OUTFLOW DURING THE SURVEY MONTH FOR FALL MIDWATER TRAWL SURVEY, 1967 TO 1988
For arcsine transformed percentages, $r^2 = 0.64$ for September, 0.76 for October, 0.71 for November, and 0.34 for December.
Source: Sweetnam and Stevens 1993.

ranged from below Suisun Bay (wet years) to above Rio Vista (critically dry years).

The entrapment zone provides habitat for species that reside in or nearby it. It may also serve as a food supply region for consumer species such as fish. The entrapment zone has been found to contain elevated concentrations of juvenile striped bass and some species of phytoplankton and zooplankton (Arthur and Ball 1980). Moreover, annual measures of several estuarine resources seem to be related to the position of the entrapment zone in the estuary. Jassby (1993) found statistically significant relationships between 2 ppt isohaline position as an indicator of entrapment zone location and the abundance of phytoplankton and phytoplankton-derived carbon; survival of larval striped bass; and abundance of mollusks, mysids, Crangon shrimp, longfin smelt, juvenile striped bass, and starry flounder. Mechanisms for these relationships are not well understood. Similar relationships have also been found with total Delta outflow (Armor 1992).

Moyle *et al* (1992) observed that in 1981 through 1988, delta smelt appeared to be most abundant in low-salinity water near the entrapment zone, except when they were spawning.

Obrebski (1993) compared delta smelt abundance from the tow-net and midwater trawl surveys to 2-ppt isohaline position (X2). The tow-net data included June-August of 1959-1965 and 1969-1991, the periods for which data were available. The midwater trawl included September to December of 1967-1973, 1975-1978, and 1980-1990. Not all of the included months were represented each year.

Data were analyzed as both the log of the delta smelt indices and as a concentration index obtained by weighting abundance indices by the volume of each subarea of the estuary where sampling was performed. A monthly estimate of the 2-ppt salinity isohaline from Kimmerer and Monismith (1993) was used to represent entrapment zone position.

Regression analysis using linear and quadratic methods were not significant for the tow-net data. The midwater trawl data were significantly related to both monthly and annual abundance indices using linear and quadratic regressions (Table 2). However, entrapment zone position explained little of the variance (16-26 percent) and the results are confounded by statistical problems. The significant Durban Watson statistic for each regression (Table 2) indicates autocorrelation in the data, which could result in erroneously high significance levels. (Similar autocorrelation problems may also be present in other analyses in this report using abundance data.) A likely cause of autocorrelation in the data is stock-recruitment effects. As discussed later in this chapter (under "Spawning Stock Size and Year-Class Strength"), there is a significant stock-recruitment relationship for the midwater trawl data. Kimmerer (1992b) analyzed the same database and found that X2 was not significantly related to abundance when stock-recruitment effects were removed. A lack of relationship between midwater trawl indices and September-December X2 position is consistent with the observation of Stevens *et al* (1990) that year-class strength appears to be set before July. As a result, it cannot be concluded that there is a relationship between delta smelt abundance and entrapment zone position.

This is consistent with the finding that there is no similar relationship between abundance and outflow, the major factor determining X2 position.

Midwater trawl and entrapment zone data have also been used as the basis for a hypothesis about the preferred geographical range of smelt (Obrebski 1993; USFWS 1993). If midwater trawl data are grouped based on when the entrapment zone was in three broad areas of the estuary (<71 km, 71-81 km, and >81 km from the Golden Gate Bridge), it appears that September-to-November abundance has been somewhat higher over a broad range of salinities when X2 was in the middle estuary. One interpretation is that smelt survive best when the entrapment zone is in this "preferred" region. However, this conclusion is dubious because of autocorrelation between entrapment zone location and midwater trawl data.

Larval Transport

It is thought that after hatching, larval delta smelt float to the surface and drift downstream toward the entrapment zone (Stevens *et al* 1990; Moyle *et al* 1992). Outflow may affect the speed at which larval fish are transported downstream. An increase in transport time may adversely affect delta smelt, which spawn upstream and depend on currents to distribute their larvae throughout the nursery area.

Table 2
SUMMARY OF RELATIONSHIPS BETWEEN SMELT ABUNDANCE AND POSITION OF THE ENTRAPMENT ZONE USING MIDWATER TRAWL DATA

Variable Type	Number of Observations	Linear Coefficient	Quadratic Coefficient	Adjusted r^2	p>F	Durbin Watson	Maximum Kilometers
Log Abundance	84 Monthly	0.044	-0.0003	0.16	0.0003	0.971	73
Log Index	84 Monthly	0.305	-0.0022	0.22	0.0003	0.822	69
Log Index	22 Annual	0.077	-0.0005	0.20	0.0442	1.199	73
Log Abundance	22 Annual	0.589	-0.0040	0.26	0.0208	0.942	73

The DWR Particle Tracking Model can be used to examine the relative importance of potential transport mechanisms in the Delta, which are governed by tidal motion (advection), dispersion, and channel braiding (see "Reverse Flows"). Model simulations indicate that high flows released in the upper Sacramento River had a great effect on average daily velocity in the upper portion of the river but made little difference in average velocity in the western Delta. Although high outflows can transport more fish to Suisun Bay, the effectiveness of high outflows on the transport process diminishes rapidly as the flow approaches the western Delta.

Reverse Flow

The magnitude and direction of flow through Delta channels are determined by inflows, channel capacities, agricultural diversions, SWP and CVP pumping, and especially tides. Twice a day, high tides push Delta water upstream. The intensity of tides varies monthly and seasonally. Although tidal flow is most pronounced in the western Delta, it is also significant in the interior Delta. For example, flow over a tidal cycle during the summer can be hundreds of thousands of cubic feet per second in the western Delta, tens of thousands in the central Delta, and thousands in the eastern Delta (Figure 29). If the tidal effects on flow are removed, a net flow will remain that will affect the direction and distance a water molecule, plankton, and possibly even very small fish may move in the channel over an extended period if they remain suspended in the water column.

The interaction of water diversions and inflows can also affect the direction of flow in Delta channels. When inflow from upstream tributaries is insufficient to meet exports and agricultural diversions, the pumps and siphons pull water from downstream areas. This can intensify upstream tidal flow in some channels, and also cause net upstream or "reverse" flows where they would not otherwise occur. Net reverse flows are most common and greatest in southern and western Delta channels during summer and fall, when nearly all the CVP and SWP exports are drawn across the Delta from the Sacramento River (Figure 29). However, reverse flow can occur any time southern Delta diversions are higher than San Joaquin inflow.

Because flow in the western Delta is usually dominated by tidal flow, net flow is difficult to measure directly. As a consequence, nearly all analyses of the effect of net reverse flow on fishery resources have used a calculated value called QWEST as an index of net reverse flow in the lower San Joaquin River. QWEST is reported in the DWR DAYFLOW database, and is the sum of flows from the San Joaquin River, the eastside streams, and the Sacramento River through Georgiana Slough and the Delta Cross Channel, minus CVP and SWP exports from the southern Delta and 65 percent of net channel depletions in the Delta. Average monthly QWEST values for 1978 to 1990 are shown in Figure 30.

Effect of Reverse Flow on Delta Smelt Abundance

The effect of net reverse flow on the movement of fish and their food supply has been a concern since construction of the Central Valley Project and the State Water Project in the 1950s and 1960s.

There is some evidence that net reverse flow might be a factor for juvenile striped bass and salmon smolts. Wendt (1987) found a weak inverse relationship between QWEST and the number of young striped bass salvaged at Banks Pumping Plant in June and July. USFWS (1992) also reported a weak relationship between QWEST and survival of salmon smolts and suggested the relationship could be partly due to increased entrainment of smolts with reverse flow. However, validity of the latter relationship has been questioned, because a narrow range of flows was analyzed and calculated flows did not take tidal effects into account (Brown and Greene 1992).

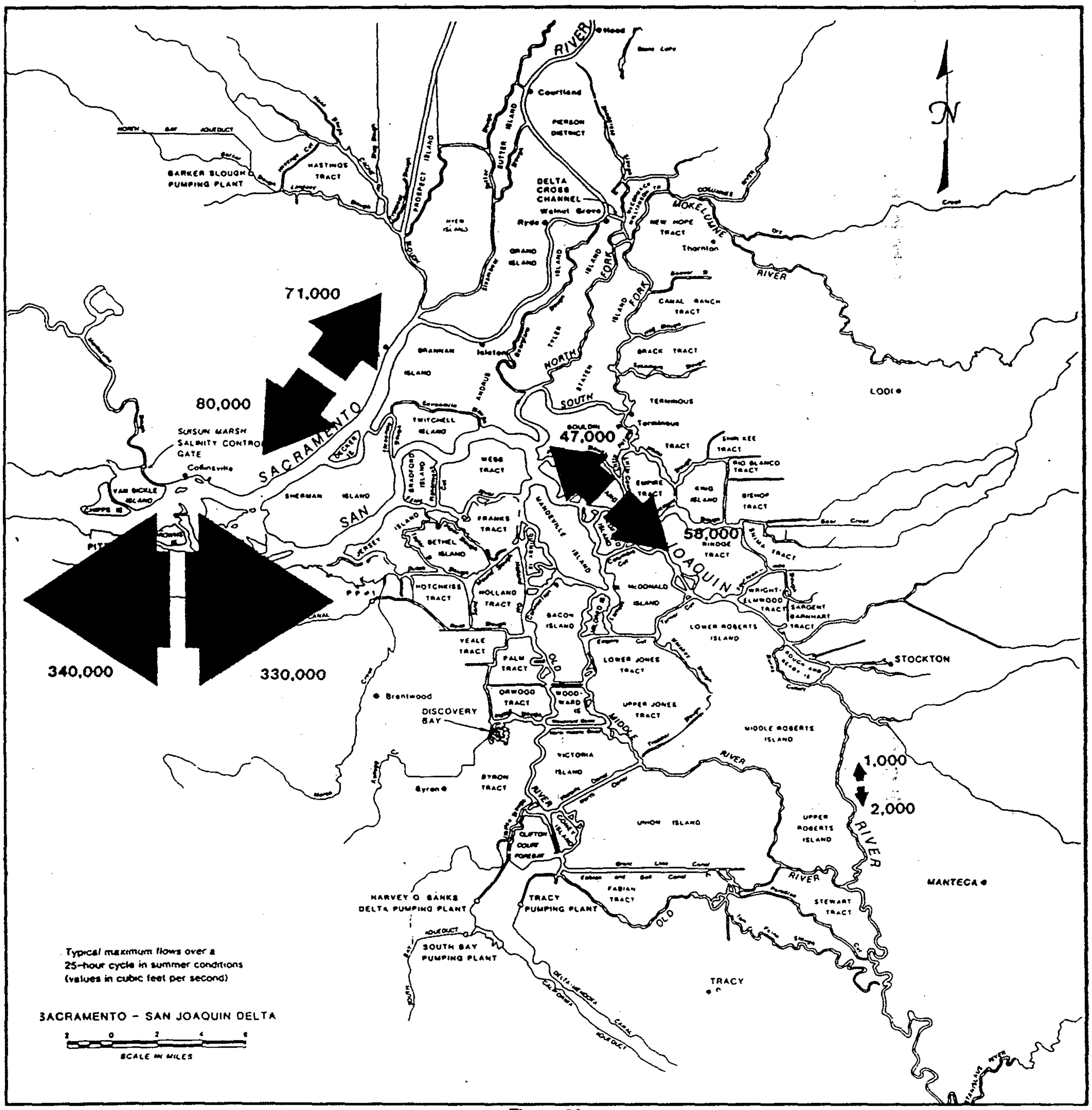

Figure 29
TIDAL FLOWS IN THE SACRAMENTO-SAN JOAQUIN DELTA

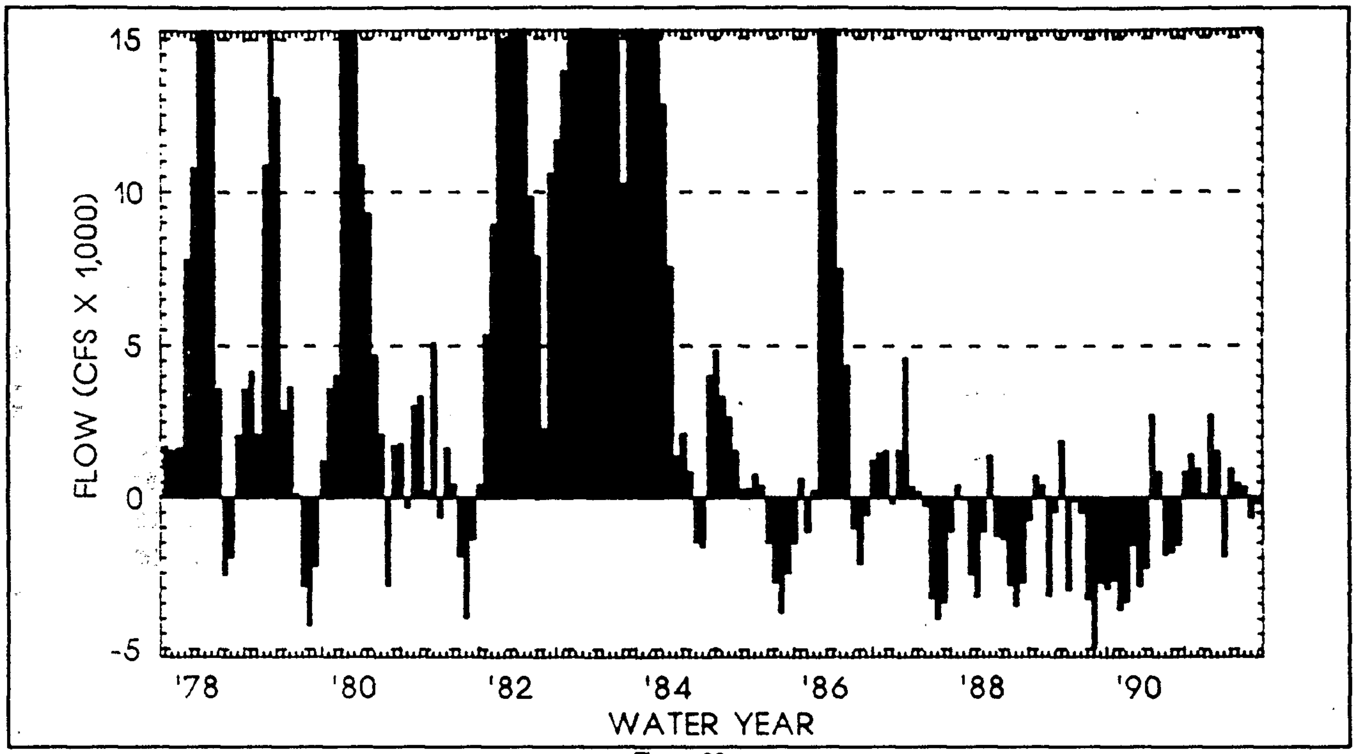

Figure 30
AVERAGE FLOW PAST JERSEY POINT (QWEST), WATER YEARS 1978 TO 1990
From the DAYFLOW Database

Several analyses of delta smelt data did not indicate any apparent relationship between QWEST and smelt abundance or entrainment at CVP or SWP facilities. The Department of Fish and Game used multiple regression analyses to examine reverse flow and several other factors that could affect delta smelt abundance (Stevens *et al* 1990). The number of days that QWEST was negative was used as the measure of reverse flow in the lower San Joaquin River. QWEST was analyzed individually and in combination with other environmental variables to identify potential effects on the summer tow-net index (March-June variables) and fall midwater trawl index (March-June, July-October variables). None of the analyses that included reverse flow as a variable explained a significant amount of variability in smelt abundance.

Moyle and Herbold (1989) indicated that low delta smelt populations (fall midwater trawl data) were associated with the number of days of negative values of QWEST. However, their analysis found no statistical association between delta smelt abundance and the number of days of reverse flows. Nevertheless, they observed that years of high smelt abundance usually had positive flow in the lower San Joaquin River and years of low smelt abundance usually had a higher number of days of reverse flows. They concluded, therefore, that the frequency of reverse flow in the lower San Joaquin River was probably limiting smelt recruitment but that it was not a simple direct relationship.

Moyle *et al* (1992) found that until 1984, water years[1] with 100 days of reverse flow were sporadic and rarely occurred during the delta

1 A water year begins October 1 and ends the following September 30.

smelt spawning season (February to May). From 1985 to 1989, reverse flows have characterized the lower San Joaquin River for more than 150 days of the year, and in every year except 1986, reverse flows have occurred for 15 to 85 days of the spawning season. An updated version of this analysis indicates that from 1990 to 1992 reverse flows continued during the delta smelt spawning season (Figure 31).

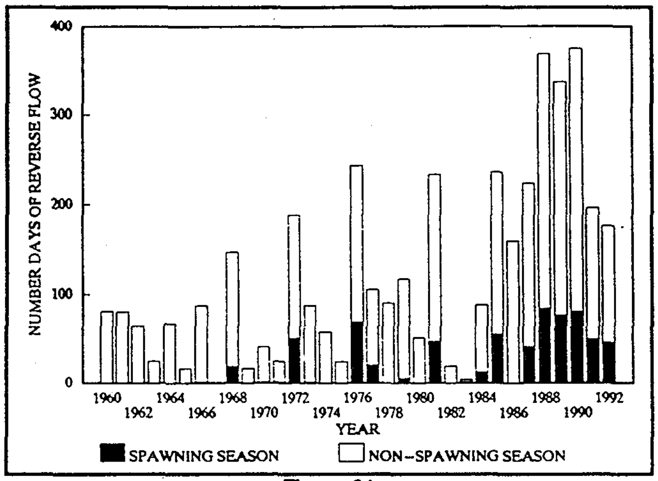

Figure 31
NUMBER OF DAYS OF REVERSE FLOW IN THE SAN JOAQUIN RIVER DURING WATER YEARS 1960 TO 1992
The black portion of each bar shows the number of days during the delta smelt spawning season (February to May).

The Department of Water Resources could not find a statistical relationship between the number of days of reverse flow and the delta smelt midwater trawl index (1967-1992) or tow-net index (1959-1993). Regression analysis did not show a significant association between the annual occurrence of reverse flow and the midwater trawl index (r^2=0.12; n=24) or the tow-net index (r^2=0.021; n=31). The association was also not significant between reverse flow during the major spawning period (February to May) and the midwater trawl index (r^2=0.12; n=24) or the tow-net index (r^2=0.037; n=32).

These relationships were also examined using Spearman's rank correlation test. No significant correlation was found between the annual occurrence of reverse flow and the midwater trawl index (r=-0.29; n=24) or the tow-net index (r=-0.19; n=31). Also, no significant correlation was found between reverse flow during the February-to-May spawning season and the midwater trawl index (r=-0.31; n=24) or the tow-net index (r=-0.33; n=32).

Visual observation of the influence of water year type (critical, dry, below normal, above normal, wet) on delta smelt abundance indices suggests that index values may be lower in dryer years than in about half the wetter years (Figures 32 and 33). However, Spearman's rank correlation test showed no significant correlation between water year type and either the midwater trawl index (r=0.32; n=24) or the tow-net index (r=0.16; n=32). In addition, a comparison of indices grouped as dry or wet years found no significant difference

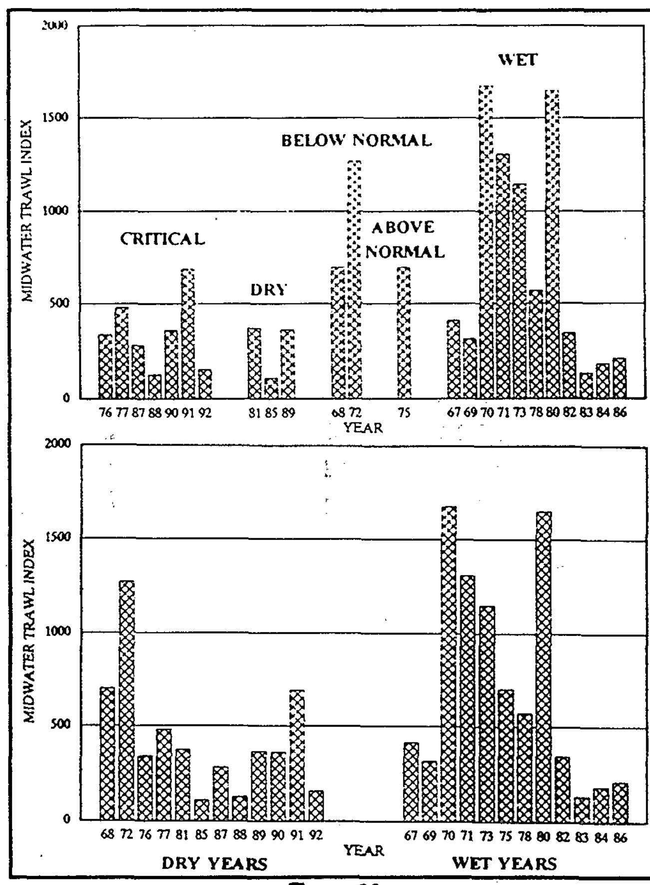

Figure 32
DELTA SMELT FALL MIDWATER TRAWL INDICES GROUPED BY WATER YEAR TYPES

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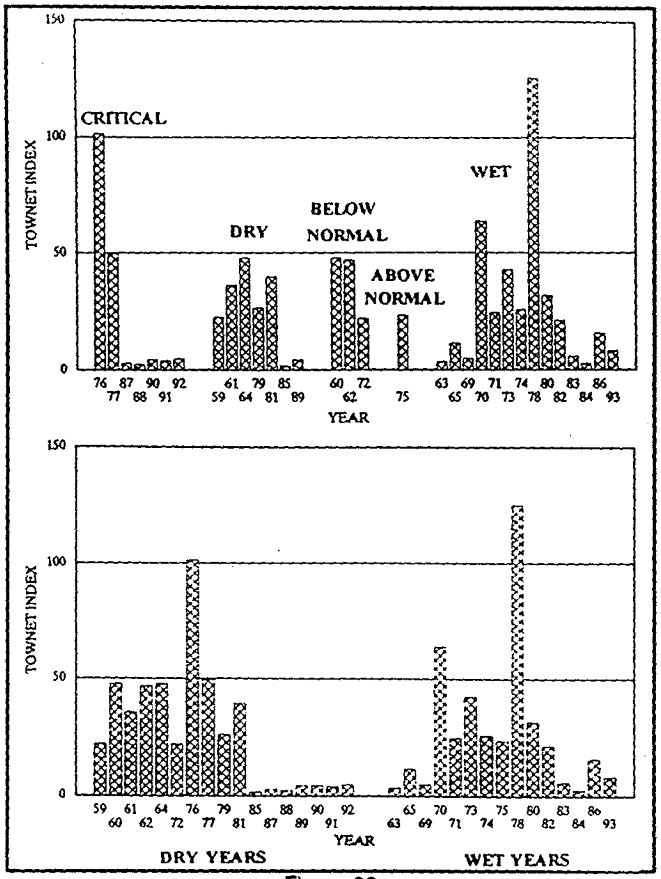

Figure 33
DELTA SMELT SUMMER TOW-NET INDICES
GROUPED BY WATER YEAR TYPES

between the midwater trawl index (Mann-Whitney U; p=0.12, n=12) or the tow-net index (Mann-Whitney U; p=0.47) of dryer years and those of wetter years.

QWEST and Fish Transport

QWEST is being used as a regulatory parameter to limit movement of winter-run Chinook salmon and delta smelt toward the CVP and SWP pumps[1]. Use of QWEST is partly driven by the perception that transport of small fish is largely dictated by QWEST.

Moyle *et al* (1992) propose that reverse flows draw young fish to the export pumps from spawning and nursery areas in the central and western Delta. Although DWR egg and larval surveys suggest that at least some smelt larvae are drawn to the pumps from the central Delta, these fish may have also originated from spawning in the southern Delta (Spaar 1993a).

Because of its possible importance, this issue was examined in further detail using simulation models. As will be shown, QWEST does not appear to be an appropriate parameter to control transport and entrainment of young fish in the Delta.

The Department of Water Resources recently examined the importance of reverse flow as a transport mechanism using the DWR Particle Tracking Model (Chung and Smith 1993). The model was developed to simulate how different flows are likely to affect the movement of neutrally buoyant particles at various locations in the Delta. The major processes simulated in the model under different flow conditions are advection, dispersion, and channel braiding.

The Particle Tracking Model used hydrology from the DWR statewide water simulation model, DWRSIM (see Chapter 6), to develop general operations criteria. For this analysis, Decision 1485 standards and 1995 hydrology were used with three levels of QWEST: 1,865, 146, and –1,724 cubic feet per second. Delta outflow was held constant at 5,485 cfs throughout the simulation. Flow and velocity patterns were simulated using the DWR/RMA Delta Hydrodynamics Model (DWR 1992c). The fate of particles introduced at 19 locations in the Delta were then examined using the Particle Tracking Model.

Results of a preliminary set of model simulations are summarized below. The results should be interpreted with caution, because

1 Discussed in Chapter 4.

delta smelt are not neutrally buoyant particles Nonetheless, the model provides an indication of the general processes likely to affect young fish.

- High Sacramento River flows greatly affected average daily velocity in the northern Delta but had little effect on average velocity in the western Delta. As a result, the effect of high flows on the transport process diminishes rapidly as the flow approaches the western Delta.
- Particles in the interior of the Delta were entrained by CVP and SWP pumps and agricultural diversions despite high positive QWEST values. This suggests that QWEST is not a good indicator of entrainment losses in the interior delta. It is conceivable that the export pumps have a "zone of influence", and a large percentage of particles within it are likely to be entrained regardless of QWEST. Further model studies are being designed to characterize the likely zone of influence at different tributary inflows, export pumping, Delta Cross Channel gate operations, Clifton Court Forebay gate operations, and consumptive uses.
- Particles in areas west of Antioch were not greatly affected by negative QWEST (–1,724 cfs). This further shows that QWEST is not a good indicator of transport processes in the western Delta.

Diversion and Entrainment

All life stages of delta smelt are vulnerable to entrainment in water diversions of the Central Valley Project, State Water Project, Pacific Gas and Electric Company's power generating plants, Delta agricultural diversions, and industrial diversions near Suisun Bay and the Delta.

Central Valley Project

Central Valley Project facilities in the Delta include Tracy Pumping Plant, Contra Costa Canal, and the Delta Cross Channel. These facilities are described in Chapter 4. Their possible effects on delta smelt are reviewed below.

Tracy Pumping Plant

The most apparent effect of the Central Valley Project is entrainment of fish at Tracy Pumping Plant. Delta smelt are eaten by predatory fish in front of and within the Tracy Fish Facility. Others are lost as they pass through the screens and during handling and trucking in the salvage process. Losses of juvenile and adult delta smelt at the fish facility cannot be calculated with certainty, because there is no information for delta smelt pre-screening losses (predation rates) or on efficiency of the louver screens for delta smelt (Sweetnam and Stevens 1993). Estimates of annual delta smelt salvage and concerns related to the salvage data are presented in Chapter 3.

Several studies suggest survival of salvaged delta smelt is probably low due to the stress of handling and trucking. Survival of 2,590 delta smelt salvaged from June 22 to July 27, 1989, and held at the SWP Byron growout facility was reported to be zero (Odenweller 1990). There was no indication of how long these smelt were held before they died. Initial field collections of brood stock to develop culture methods for delta smelt found most died within 48 hours using various netting techniques (Lindberg 1992). A modified purse seine technique was finally successful, with 88 percent survival in March 1992 and 10 to 47 percent survival in mid-April 1992.

Handling and transport mortality can be reduced by cooling and reducing the sloshing of water during transport (Mager 1993). Stress-related handling and trucking mortality can also be reduced by adding salt to transport water. A solution of 3 ppt has been determined to reduce stress without causing problems for salt-intolerant species such as delta smelt (Odenweller 1990).

Although exact levels of delta smelt losses are not known, salvage and egg and larval data do indicate the timing and relative magnitude of project impacts. Evidence from Tracy Fish Facility and from egg and larval surveys are summarized below.

It should be emphasized, however, that there does not appear to be a simple relationship between project operations and abundance. As evidence, Stevens *et al* (1990) analyzed water exports individually and in combination with other environmental variables for potential effects on the summer tow-net index (March-June variables) and fall midwater trawl index (March-June, July-October variables). None of the analyses found that the level of combined CVP/SWP exports explained a significant amount of variability in smelt indices.

Juveniles and Adults

Salvage data (monthly averages) indicate entrainment of juvenile and adult delta smelt is usually greatest during spring and summer, reflecting the late winter-spring spawning season and growth and mortality of young-of-the-year fish (Sweetnam and Stevens 1993) (Figure 34).

May through August appears to be a period of high salvage at the CVP, with a peak in May. Juveniles are usually collected from late February to August and adults from December through April (Figure 35). The near-ripe condition of adults collected from late December 1990 to April 1991 indicates they were salvaged during spawning migration (Wang 1991). In 1993, juvenile delta smelt were salvaged at the CVP in mid-May and again in late May through early July (Figure 36).

Between 1979 and 1991, salvage in spring and summer was lowest in 1983, 1986 (both wet years), 1991, and 1992 (both critical years). Annual salvage was lowest in 1979, 1981, and 1987 (all drought years), and 1984 (wet year).

One factor that may influence delta smelt is year-class strength. In years when delta smelt are more abundant in the system, entrainment losses could increase. One approach to examine this issue is to develop an index that incorporates year-class strength. To achieve this end, salvage data for each cohort were divided by the summer tow-net index. Cohorts were identified at the SWP using length data to differentiate salvaged adults from young-of-the-year smelt. These data have not yet been analyzed for the CVP, so salvage levels for April through March of the following year were assumed to represent a single cohort. As an example, in June 1984 the summer tow-net index was 1.3 and 5,866 delta smelt were salvaged, so the resulting index is 5866/1.3 = 4512.

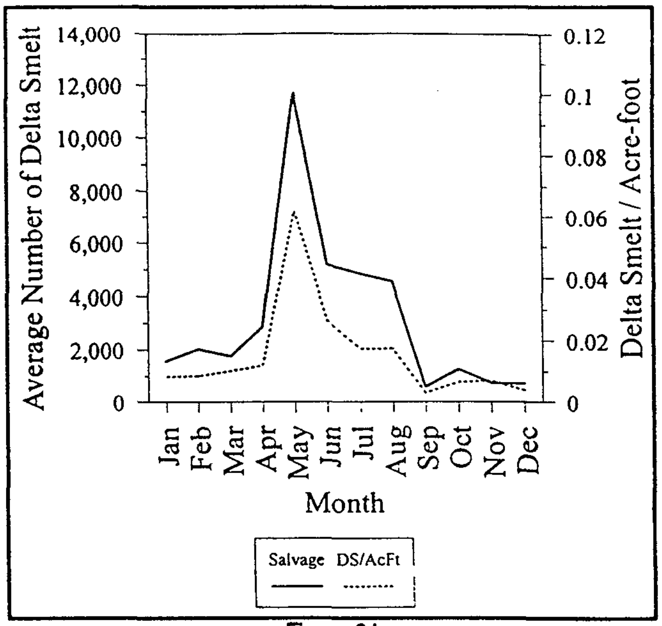

Figure 34
MONTHLY AVERAGE ESTIMATED DELTA SMELT SALVAGED AND SMELT SALVAGED PER ACRE-FOOT EXPORTED BY THE CVP TRACY PUMPING PLANT, 1980 TO 1991
Source: Sweetnam and Stevens 1993.

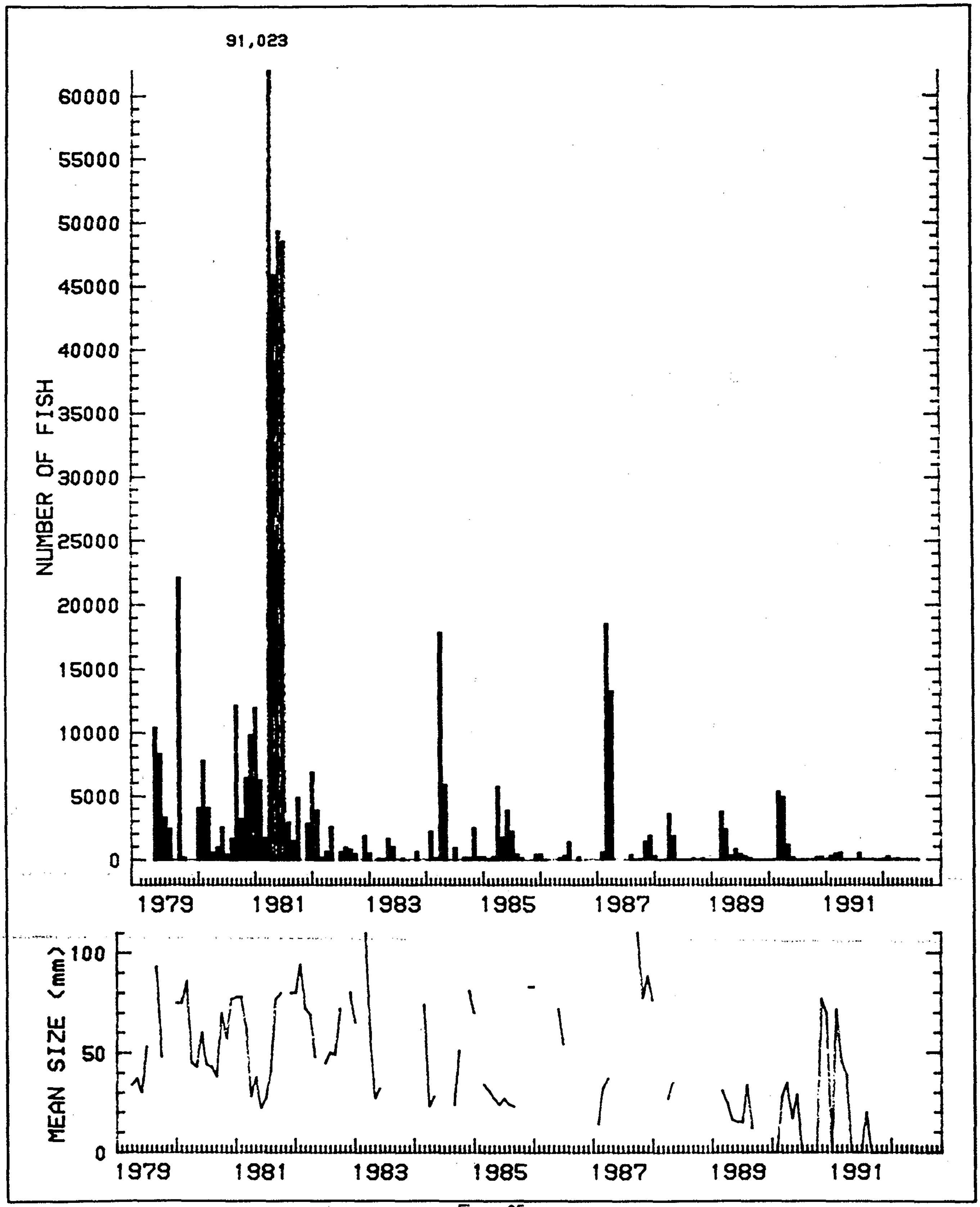

Figure 35

EXPANDED NUMBER AND MEAN SIZE OF DELTA SMELT SALVAGED MONTHLY AT TRACY FISH FACILITY, 1979 TO 1992

In this discussion, the index is referred to as "entrainment index" rather than "salvage index" to avoid confusion with actual salvage numbers. The concept is similar to the loss rate index developed for striped bass by the Department of Fish and Game (Kohlhorst *et al* 1993). However, the loss rate index is based on calculated losses of striped bass, and the entrainment index for delta smelt uses salvage as an index of losses. By incorporating year-class strength, both indices provide a relative measure of when impacts are likely to be greatest at the population level. For example, losses are likely to be more detrimental to the population when elevated losses coincide with a weak year-class. A possible bias with these indices is that the summer tow-net index may not completely represent year-class strength because it may partly reflect some entrainment losses in the previous spring. The entrainment index also does not take into account seasonal changes in predation and screening efficiency, which could result in variation in salvage levels. Without this information, actual losses and entrainment levels cannot be determined.

Estimated Central Valley Project entrainment indices are presented in Figure 37. Results are generally consistent with CVP salvage (Figure 35). Indices were low in most wet years (1980, 1982, 1983, 1986, 1993) and high in most drought years (1981, 1985, 1987-1990). The high index in 1984 and low indices in 1991 and 1992 are exceptions that might be better understood on further examination of outflow and monthly distribution of delta smelt sizes.

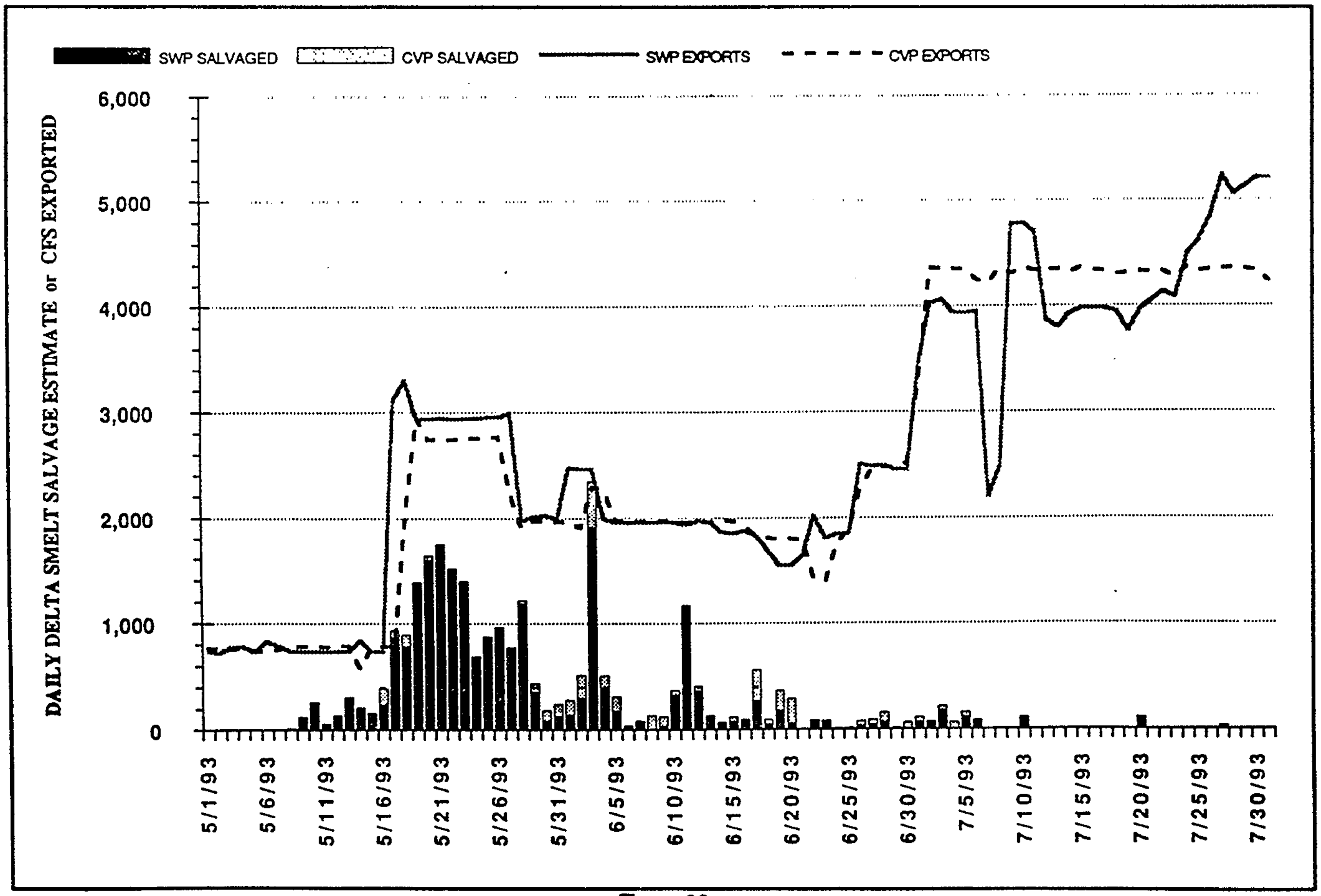

Figure 36
DAILY DELTA SMELT SALVAGED AND DELTA EXPORTS AT THE
STATE WATER PROJECT AND CENTRAL VALLEY PROJECT, MAY AND JUNE 1993

Although results suggest project impacts may have often been greater in drier years than in wet years, they do not show whether project operations significantly reduced the delta smelt population. The data do show the relative magnitude of project impacts between years.

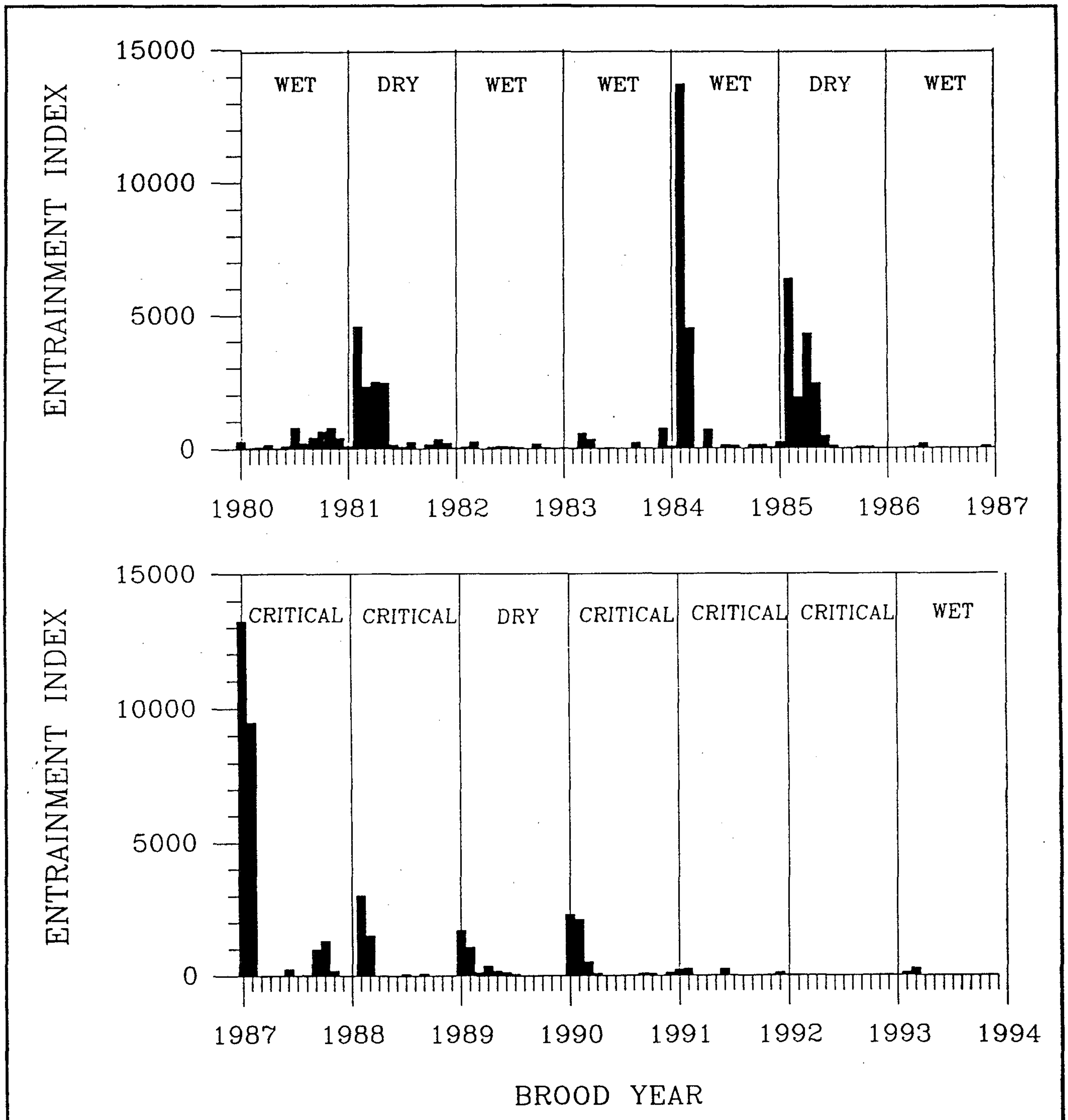

Figure 37
DELTA SMELT ENTRAINMENT INDICES AT TRACY FISH FACILITY FOR 1980-1993 BROOD YEARS, APPROXIMATED FROM APRIL-TO-MARCH SALVAGE
Water year types (from Decision 1485) represent the hydrology when the brood year was set.

Eggs and Larvae

Information on Central Valley Project entrainment of delta smelt larvae is available from the DWR Egg and Larval Entrainment Study for 1989 to 1992. Larval smelt entrainment was estimated beginning in 1989, when positive identification of all sizes of larval delta smelt became possible. Seven sites are sampled in the southern Delta (Sites 91-96, 98) and five sites were added in the central Delta in 1992 (Sites 930-934) (Figure 38).

In general, delta smelt larvae may be present in the southern Delta from late February through early June, but occurrence may vary within this period from year to year. There is apparently little spawning in this area. Fewer smelt are caught here and over a shorter seasonal distribution compared to areas of high abundance on the Sacramento and San Joaquin rivers. In 1992, no smelt larvae were caught at the southern Delta sites after April 12; at the central Delta sites, larvae were caught until June 7 (Spaar 1993a). Smelt larvae may

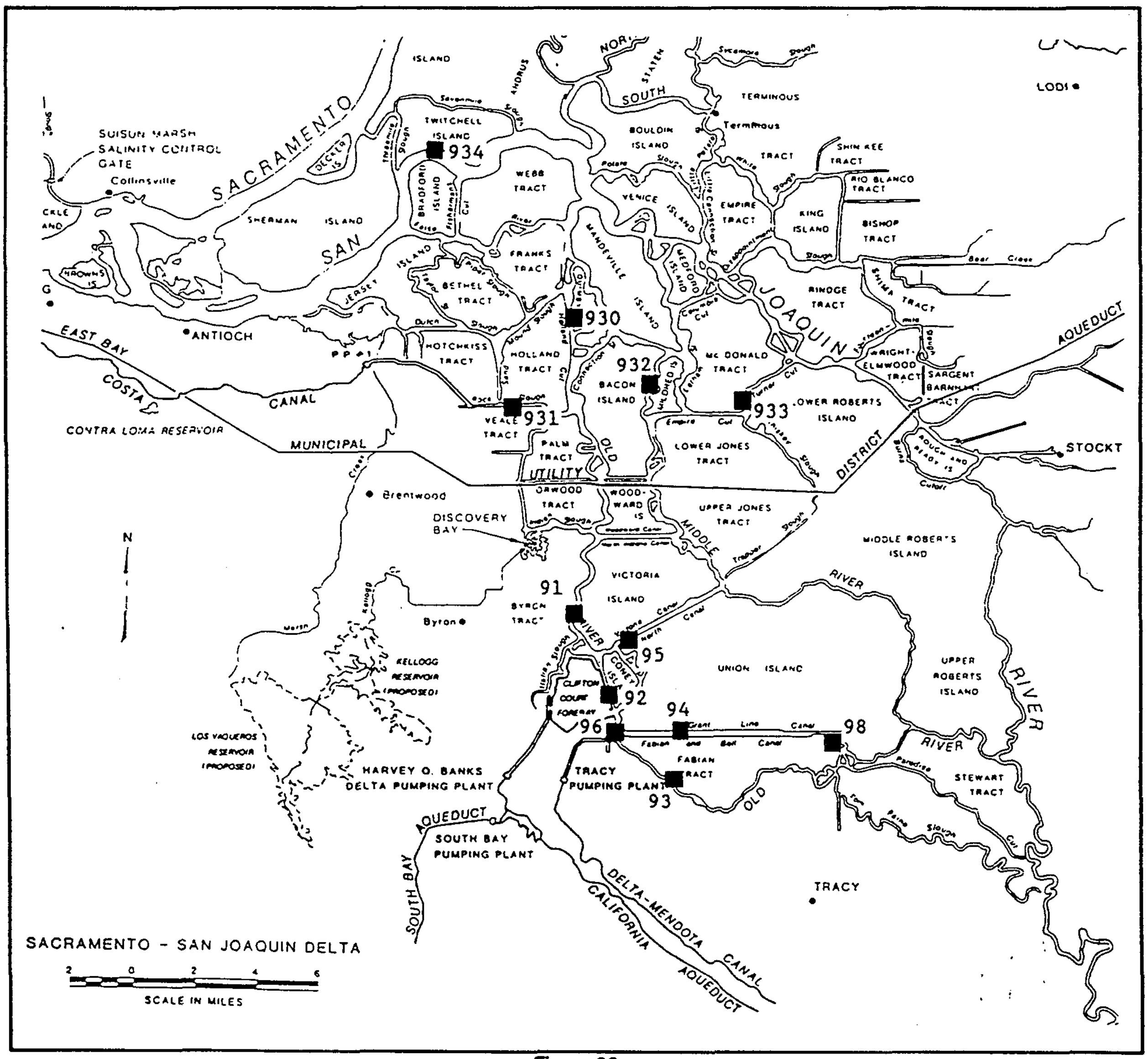

Figure 38
DELTA EGG AND LARVAL ENTRAINMENT STUDY SITES IN THE SOUTHERN DELTA AND AGRICULTURAL DIVERSION STUDY EGG AND LARVAL SITES IN THE CENTRAL DELTA

have been present in the southern Delta during periods in April (18-26) and May (12-24) when bridge repairs rendered this area inaccessible to the survey boat. Sampling continued in both the southern and central Delta into July. The average catch per unit effort of delta smelt larvae at the central Delta sites exceeded the southern Delta catch every month (Figure 39). Preliminary data for 1993 also indicate more smelt larvae were caught at the central Delta sites than in the southern Delta.

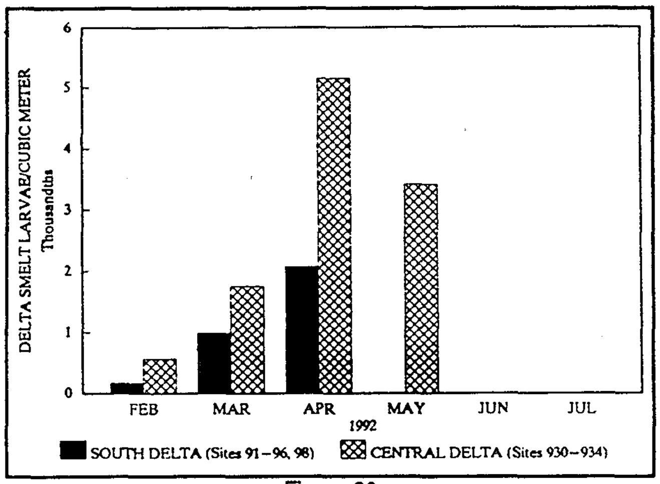

Figure 39
1992 AVERAGE MONTHLY CATCH DENSITIES OF DELTA SMELT LARVAE AT SOUTHERN AND CENTRAL DELTA EGG AND LARVAL SAMPLING SITES
(In Larvae per Cubic Meter. Larval densities were multiplied by 1000.)
For Sites 932-934, sampling began on April 6, 1992.

Entrainment estimates for delta smelt larvae (less than 21-mm long) for the CVP and SWP indicate the projects entrain about the same magnitude of larvae (Figure 40, Table 3). The SWP entrained about one-third more than the CVP during 1989 to 1992. This is probably because the SWP intake is closer to the central Delta and because the CVP takes more San Joaquin water from upstream through Old River. Reverse flows in Old and Middle rivers may transport larvae to the southern Delta, but larvae are less abundant in the southern Delta than in the San Joaquin River and central Delta. Entrainment estimates for 1993 will not be available until December 1993.

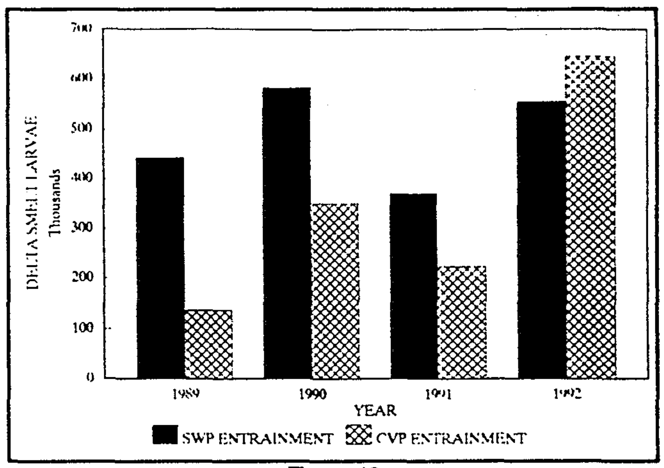

Figure 40
ESTIMATED ENTRAINMENT OF DELTA SMELT LARVAE AT THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT DELTA FACILITIES, 1989 TO 1992
1991 includes estimated entrainment for April 26 to May 26 as the mean 1989 and 1990 entrainment for the same period.

Table 3
ESTIMATED ENTRAINMENT OF DELTA SMELT LARVAE, 1989 TO 1992
(In Thousands of Fish)

Year	SWP	CVP	Total
1989	443	136	579
1990	582	349	931
1991*	24	17	41
1992	554	645	1,200
Total	1,603	1,147	2,751

* No sampling from April 16 to May 26, 1991, due to boat breakdown.

Contra Costa Canal

The Contra Costa Canal, operated by Contra Costa Water District, is an unscreened intake at Rock Slough, which draws 50 to 250 cubic feet of water per second from Old River. Larval losses would be expected whether the intake were screened or not. DWR egg and larval monitoring, which began in Rock Slough in 1992, caught larval smelt on only three days between February 20 and July 15 (Spaar 1993a). Catch densities were: 0.0082 larvae per cubic meter on March 3; 0.0051 on March 11; and 0.007 on April 8.

Preliminary data for the same period in 1993[1] indicate six larval smelt were collected on five occasions: March 2, 19, 23, and 31 and April 2. Densities are not yet available for 1993.

No abundance or loss estimates are available for juveniles or adults in Rock Slough.

Delta Cross Channel

The CVP Delta Cross Channel, completed in 1951, has two 60-foot gates at the Sacramento River to enhance transfer of water into the central Delta. Cross Channel operations could influence the upstream spawning migration of adult delta smelt or the downstream transport of larvae.

Closure of the Delta Cross Channel could provide acceptable spawning habitat similar to a dead-end slough, where delta smelt have been observed to spawn (Radtke 1966), or closure could interfere with spawning success by delaying migration. Neither effect has been documented for delta smelt.

The Delta Cross Channel is thought to decrease survival of larvae by making fish more vulnerable to SWP/CVP diversions in the southern Delta (DFG 1993). However, Wendt (1987) found no relationship between the number of bass salvaged at Skinner Fish Facility and the amount of flow through the Cross Channel. A similar analysis has not been performed for delta smelt, but a number of transport modeling studies using tracers[2] suggest that closing the Cross Channel could reduce entrainment of larvae spawned in the Sacramento River (DWR 1993a). By contrast, fish spawned in the lower San Joaquin River system could be adversely affected because closing the Cross Channel reduces the ability of flow pulses to transport tracers to downstream nursery areas (DWR 1993a). Given the conflicting results from these two systems and uncertainties about whether they apply to delta smelt larvae, the net effects are not known. It is possible, however, that impacts depend on the distribution of spawning. Wang (1991) found that the Sacramento River was not used as intensively as a spawning area as the San Joaquin River in 1989 and 1990, but the location of spawning may change annually.

State Water Project

State Water Project facilities include Banks Pumping Plant, Clifton Court Forebay, North Bay Aqueduct, Suisun Marsh Salinity Control Structure, and South Delta Temporary Barriers. These facilities are described in Chapter 4. Their possible effects on delta smelt are reviewed below.

Banks Pumping Plant

The most apparent effect of the State Water Project is entrainment of fish at Banks Pumping Plant. Delta smelt are eaten by predatory fish as they cross Clifton Court Forebay. Others are lost as they pass through Skinner Fish Facility and during handling and trucking in

1 There was no sampling from April 12 to May 20 due to boat problems.
2 Smelt do not behave like tracers, but some of the same processes may apply.

the salvage process. Losses of juvenile and adult delta smelt at the fish facility cannot be calculated with certainty, because there is no information for delta smelt pre-screening losses (predation rates) or on efficiency of the louver screens for delta smelt (Sweetnam and Stevens 1993). Estimates of annual delta smelt salvage and concerns related to the salvage data are presented in Chapter 3. Survival of salvaged delta smelt is probably low due to the stress of handling and trucking.[1]

Although exact levels of delta smelt loss are not known, salvage and larval data do indicate the timing and relative magnitude of project impacts. Evidence from Skinner Fish Facility and from larval surveys are summarized below.

Juveniles and Adults

Entrainment of juvenile and adult delta smelt has usually been greatest during spring and summer, reflecting the late winter/spring spawning season and growth and mortality of young-of-the-year fish (Sweetnam and Stevens 1993) (Figures 41 and 42). Salvage was unusually high from December 1977 through February 1978, when exports increased after the drought.

Actual losses of juvenile and adult delta smelt salvaged at the SWP cannot be calculated at this time. Losses must be back-calculated from the number salvaged and estimated percentage lost due to trucking and handling, passing through the screen, and passing through Clifton Court Forebay. Experiments to determine forebay losses have been performed only for striped bass and salmon, and there are no estimates for other species, including delta smelt. Even bass and salmon loss estimates are not precise because experiments were not conducted over all seasons, hatchery fish were used rather than wild fish, and a relatively narrow size range of fish was examined (DWR 1992a). Forebay losses are believed to be lower in winter, when the predator populations have been lower (Kano 1990a) and cooler water temperatures probably reduce the metabolic and consumption rates of predators. In addition, screening efficiency estimates for Skinner Fish Facility are based on studies in the late 1960s and do not reflect subsequent design and operational improvements. How well the available information on loss factors applies to delta smelt is not known.

For this assessment, delta smelt salvage data (length and abundance) were examined to determine the effect of SWP operations on the delta smelt population and to determine what environmental parameters influence delta smelt salvage.

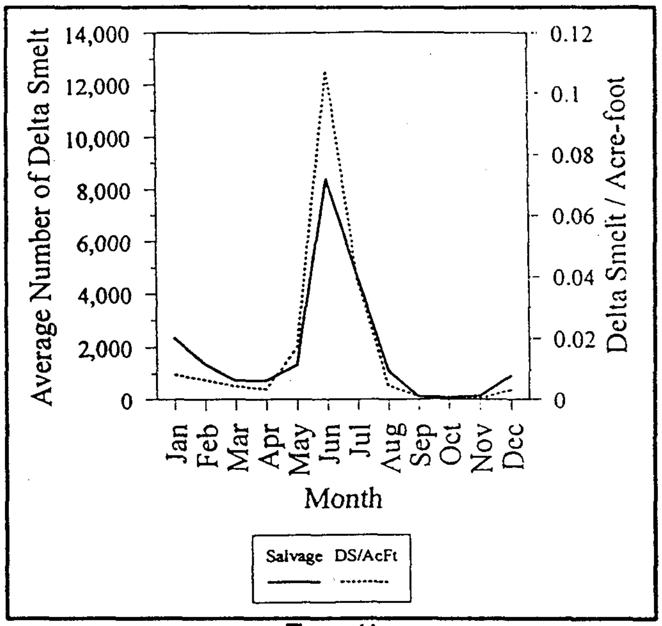

Figure 41
MONTHLY AVERAGE ESTIMATED DELTA SMELT SALVAGED AND DELTA SMELT SALVAGED PER ACRE-FOOT EXPORTED AT BANKS PUMPING PLANT, 1980 TO 1991
Source: Sweetnam and Stevens 1993.

1 Handling and transport losses are discussed under "Central Valley Project", earlier in this chapter.

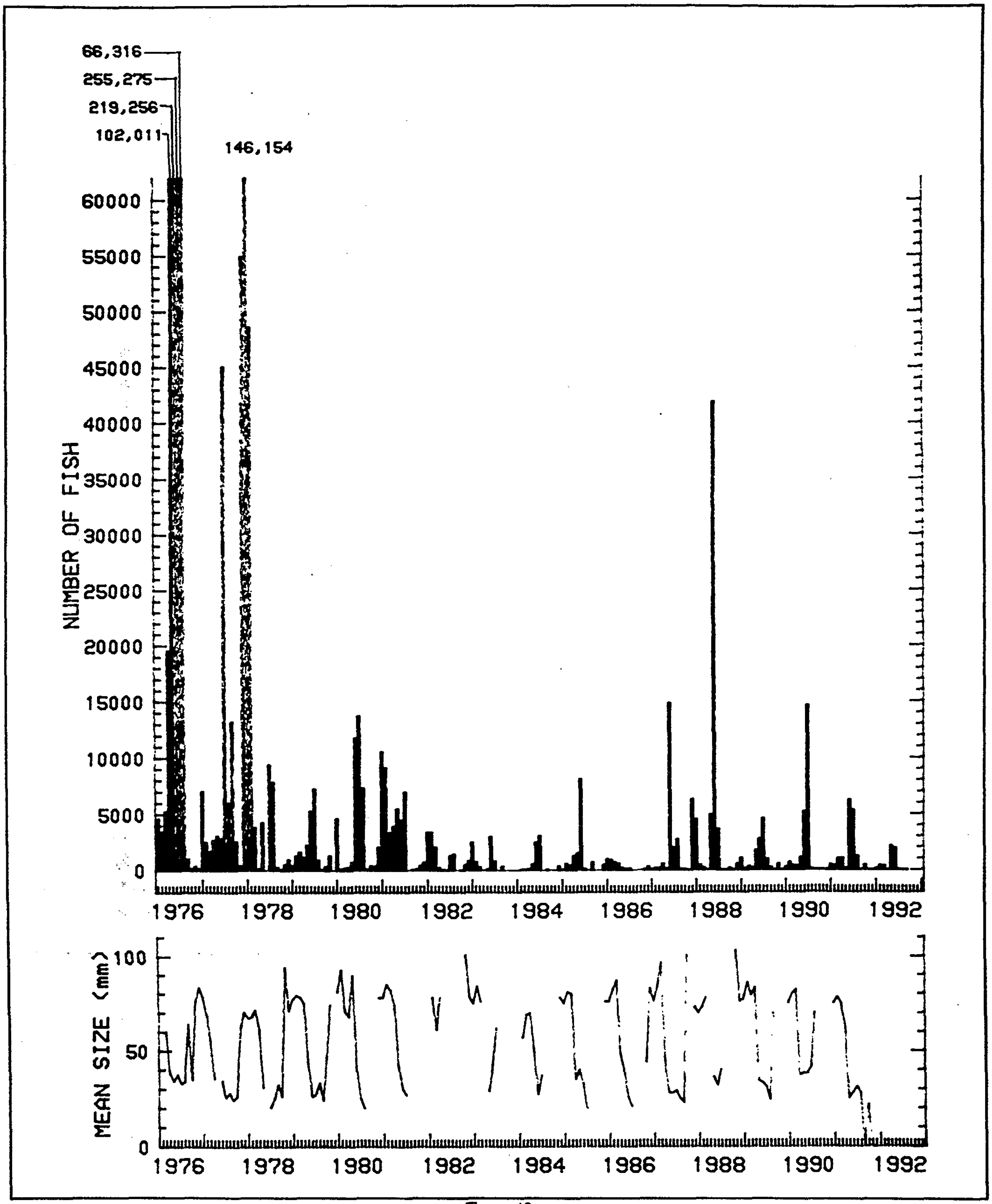

Figure 42
EXPANDED NUMBER AND MEAN SIZE OF DELTA SMELT SALVAGED MONTHLY AT SKINNER FISH FACILITY, 1976 TO 1992

Daily length frequency of delta smelt salvaged between 1979 and 1991 (the period of most accurate data) indicates there are two distinct length groups during March, April, and May, and as early as January (1981) (Figure 43). Based on life history information in Moyle *et al* (1993), delta smelt less than 50 mm salvaged in March through May were designated as juveniles (current year-class) and those 50 mm or greater were designated as adults (previous year-class). Delta smelt salvage, by year-class, plotted with Clifton Court Forebay inflow and Delta outflow indicates: many more juveniles are salvaged than adults; most juveniles are salvaged over a 2- to 4-month period; and this period varies between April through August. Before year-class 1982/1983, large numbers of both juvenile and adult delta smelt were salvaged. Since then, very few adults were salvaged except for year-class 1988/1989.

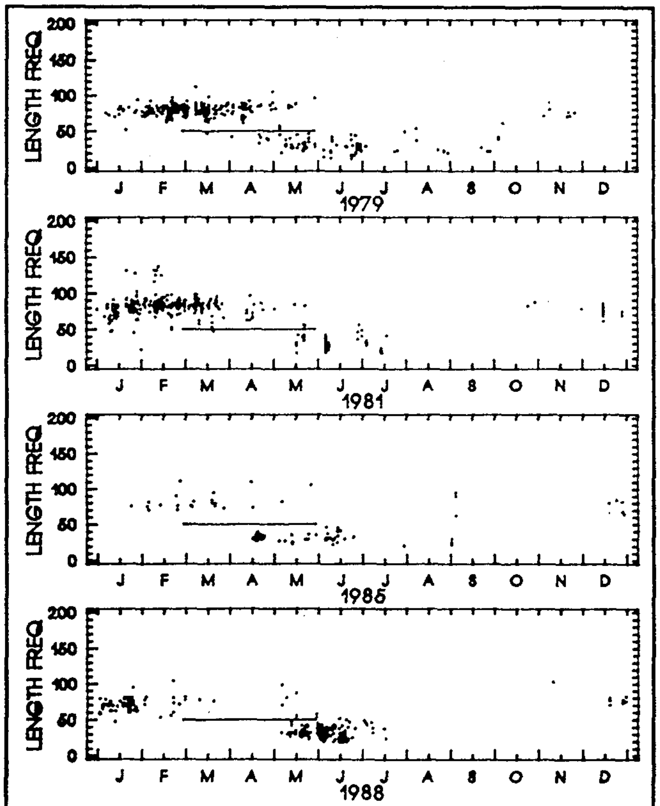

Figure 43
DAILY LENGTH FREQUENCY OF DELTA SMELT SALVAGED AT THE STATE WATER PROJECT IN SELECTED YEARS
Two year-classes of smelt are often present from late winter through spring.

The relationship between juvenile delta smelt salvage (summed for each year-class over the 2 to 4 months when most were salvaged) and Clifton Court Forebay inflow, Delta inflow, lower San Joaquin River flow, and Delta outflow (averaged over same 2- to 4-month periods) were investigated using regression analysis (Figure 44).

Two years, 1980 and 1983, produced the most variation in the regression equations. There is no apparent reason to exclude 1980 from the analysis, but the 1983 data are questionable because Delta outflow was so high that delta smelt were probably flushed out of the system and pumping was reduced dramatically in March through May. With the removal of 1983 data (Figure 45), juvenile delta smelt salvage appears to be significantly negatively related to Delta inflow ($p<0.01$, $r^2=0.56$, $N=12$), lower San Joaquin River flow ($p<0.01$, $r2=0.63$, $N=12$), and Delta outflow ($p<0.01$, $r2=0.69$, $N=12$). These data series have not yet been tested for autocorrelation problems, which may artificially elevate regression coefficients.

These relationships are consistent with the CVP salvage data (Figure 35), which frequently showed increased salvage in drought years during the same period. If CVP and SWP salvage levels are indeed linked to hydrology, a possible explanation is that the distribution of delta smelt population shifts upstream during drier years (Stevens *et al* 1990), perhaps making them more vulnerable to entrainment. A higher risk of entrainment in the interior Delta is consistent with DWR Particle Tracking Model studies (described in the previous section). While smelt may not behave like neutrally buoyant particles, the same process would tend to increase entrainment of smelt in drier years. Extent of the area affected by pumping is not known, but it could depend on tributary flows, exports, Delta Cross Channel gate operations, Clifton Court Forebay gate operations, and Delta consumptive uses.

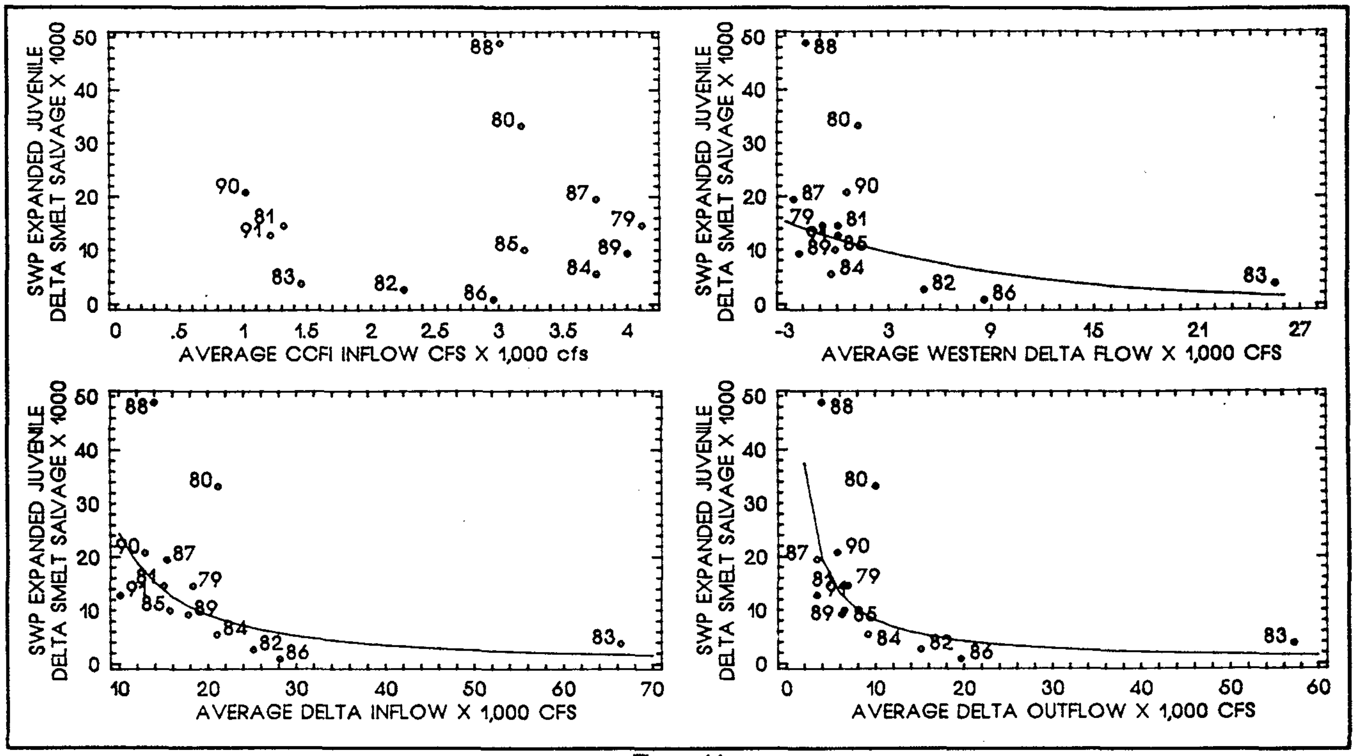

Figure 44
RELATIONSHIP BETWEEN JUVENILE DELTA SMELT SALVAGED AT SKINNER FISH FACILITY AND
CLIFTON COURT FOREBAY INFLOW, WESTERN DELTA FLOW, DELTA INFLOW, AND DELTA OUTFLOW, 1979 TO 1991 (ALL YEARS)

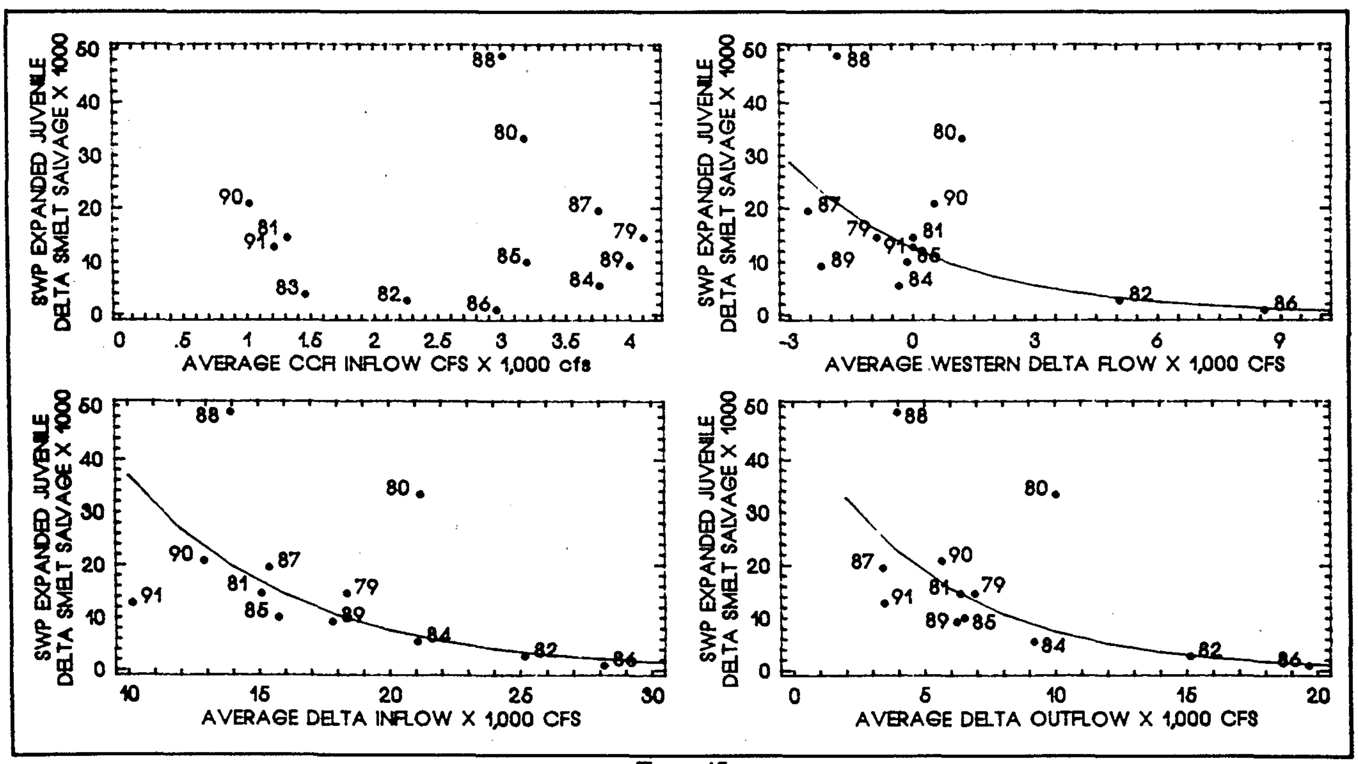

Figure 45
RELATIONSHIP BETWEEN JUVENILE DELTA SMELT SALVAGED AT SKINNER FISH FACILITY AND
CLIFTON COURT FOREBAY INFLOW, WESTERN DELTA FLOW, DELTA INFLOW, AND DELTA OUTFLOW, 1979 TO 1991 (EXCEPT 1983)

If this hypothesis is correct, one might also expect to find a relationship between Clifton Court Forebay inflow and salvage in drier years, when the population is closer to the export facilities. Figure 46 shows this relationship did not improve when wetter years (1980, 1982, 1983, 1984, 1986) were removed. A possible explanation is that patchiness in the distribution of smelt spawning and larvae has a greater influence on salvage levels than do export rates. Daily or weekly variation in exports and outflow could, therefore, be important to salvage levels and obscure any relationship with Clifton Court inflow over longer periods (2 to 4 months in this analysis). Annual variation in year-class strength, described below, could also have a major impact on salvage levels.

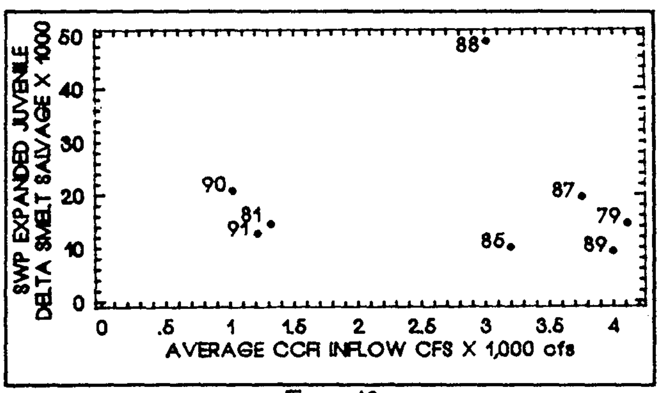

Figure 46
RELATIONSHIP BETWEEN JUVENILE DELTA SMELT SALVAGED AT SKINNER FISH FACILITY AND CLIFTON COURT FOREBAY INFLOW, 1979 TO 1991, AFTER REMOVING WET YEARS
Years Removed Are 1980, 1982, 1983, 1984, and 1986, Classified by Decision 1485 as "Wet".

State Water Project salvage was also examined using entrainment indices as a means to correct for year-class strength and to examine population level impacts. An advantage of using entrainment indices is that they remove stock-recruitment effects that could cause autocorrelation in the salvage data series. The 1979-1991 entrainment indices developed for the State Water Project are more exact than for the Central Valley Project, because size measurements were readily available to separate salvage data into brood years. Preliminary indices have also been calculated for 1992 and early 1993 using the assumption that cohorts roughly correspond to salvage in April 1992 through March 1993 and in April 1993 through July 1993. Final indices will be estimated as soon as size data are available.

Calculated entrainment indices are summarized in Figure 47. The indices are highest between May and July, representing salvage of young smelt. The smaller secondary peaks in December through February correspond to the adult smelt spawning migration. Entrainment indices were low in 1979 to 1983 and 1986. These were all wet years except 1979 and 1981, when year-class strength was relatively high (tow-net index was 13.2 in 1979 and 19.9 in 1981). Entrainment indices were higher during later drought years (1985 and 1987-1991) due to a combination of relatively high salvage rates and low tow-net indices. The low indices for 1992, a critical year, were an exception to this trend. Although the 1984 and preliminary 1993 indices were relatively high compared to other wet years, they were lower than most drier years.

In summary, SWP entrainment indices are reasonably consistent with SWP salvage data and with CVP entrainment indices. Also, SWP exports tend to take a higher fraction of the population when abundance is low and in a dry year. If the delta smelt tow-net index is relatively high, such as in 1979 and 1981, the impact of exports may be reduced in dry years. Results for 1980, 1982, 1983, and 1986 also suggest that population level impacts can be relatively small in wet years.

Entrainment indices identify the relative magnitude of project impacts between years, but do not demonstrate that operations significantly reduced abundance.

As described for the CVP, Stevens *et al* (1990) did not find a relationship between CVP/SWP exports and abundance. A possible explanation is that exports may not affect abundance indices except in drought years when cohort strength is weak. As described later in this chapter (see "Spawning Stock Size and Year-Class Strength"), year-class depends at least partly on the number of spawners during the previous year. Alternatively, the effect of exports may be small in relation to other factors that influence the population.

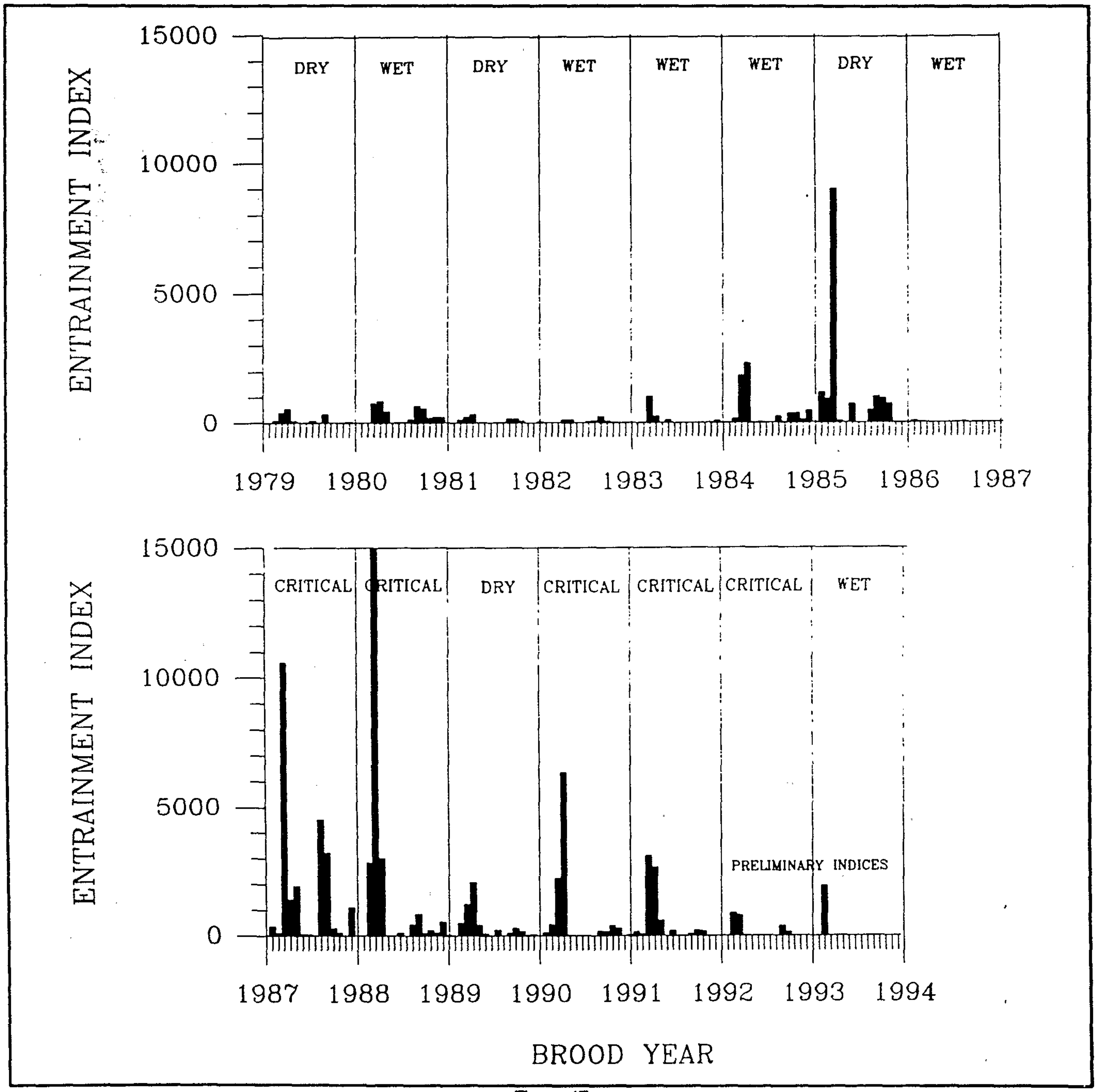

Figure 47
DELTA SMELT ENTRAINMENT INDICES AT SKINNER FISH FACILITY FOR 1979 TO 1993 BROOD YEARS, REPRESENTING SALVAGE FROM MARCH THROUGH MAY OF THE FOLLOWING YEAR
Water year types (from Decision 1485) represent the hydrology when the brood year was set.

Larvae

Information on entrainment of delta smelt larvae at the State Water Project is available from the DWR Egg and Larval Entrainment Study for 1989 to 1992 (Figure 40, Table 3). More information on larval delta smelt in the southern Delta near the SWP intake can be found in the discussion for the Central Valley Project.

Entrainment estimates for delta smelt larvae (less than 21 mm long) indicate that, overall, the SWP may entrain slightly more larvae than the CVP. This is probably because the SWP intake is closer to the central Delta. Reverse flows in Old and Middle rivers may transport larvae to the southern Delta, but larvae are less abundant in the southern Delta than in the San Joaquin River and central Delta.

North Bay Aqueduct

The Department of Water Resources contracted with the University of California, Davis, and the Department of Fish and Game to monitor fish abundance in Barker and Lindsey sloughs. DFG monitoring from June 1988 through 1990 indicates juvenile and adult delta smelt are relatively low in abundance (1.22 percent of total catch) in comparison to the more abundant species of the slough, such as striped bass (21.76%), tule perch (17.6%), white catfish (12.22%), and threadfin shad (7.82%) (Kano 1990b). The smelt ranged from 59 to 116 mm long. Relative abundance of delta smelt

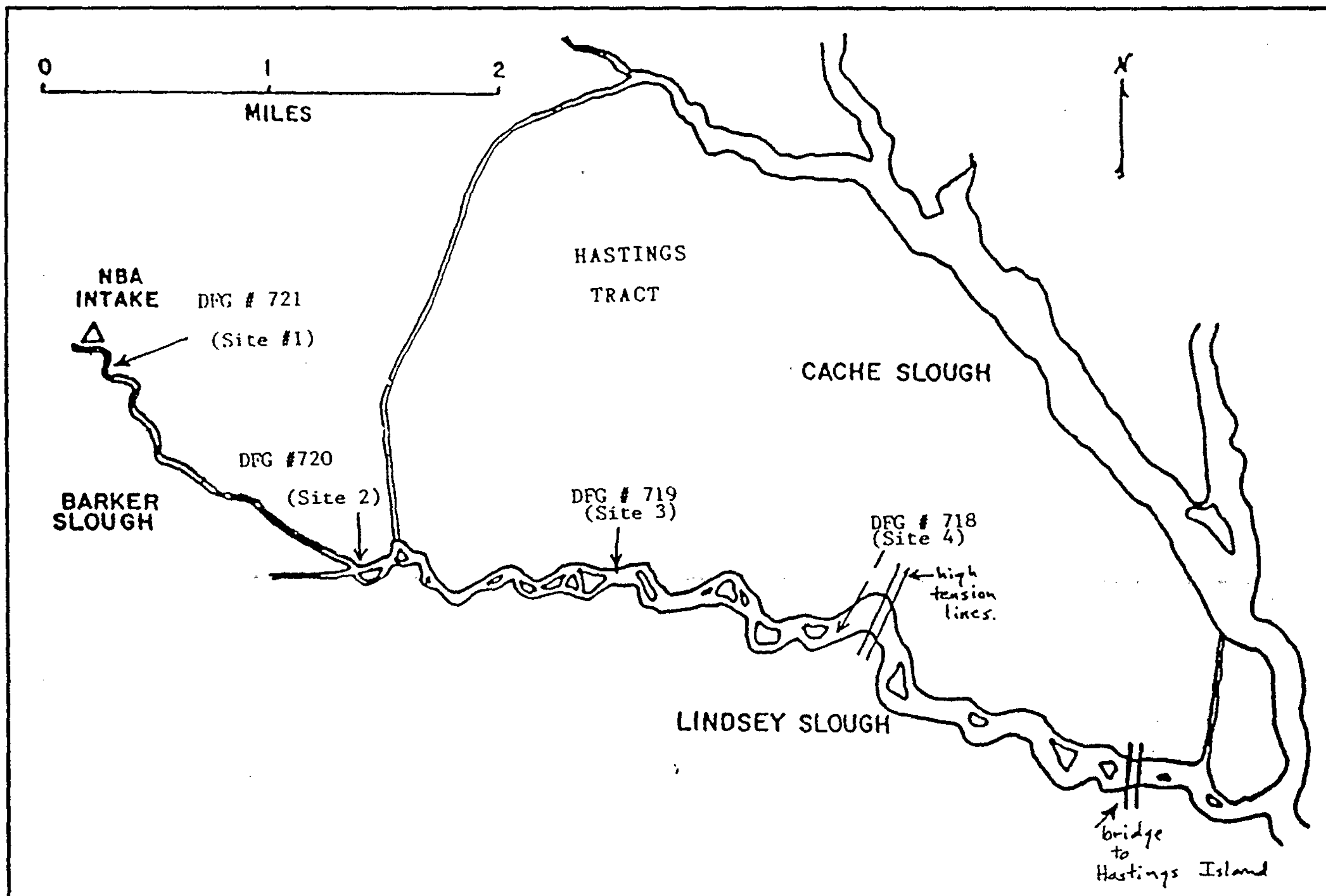

Figure 48
EGG AND LARVAL SAMPLING SITES FOR THE NORTH BAY AQUEDUCT

less than 100 mm was greater during winter (February, 0.00215 smelt/cubic meter) than in summer (June, 0.00006 smelt/cubic meter) or fall (October, no smelt). Average size of these fish was 73.8 mm. It appears that, at least in dry years, delta smelt are spawning in or near the Barker/Lindsey Slough area. One adult delta smelt (ripe female) was caught at the entrance to Barker Slough on March 15, 1991 (Bennett 1992).

Additional information on juvenile and adult delta smelt in the Cache Slough area is available from the fall midwater trawl survey and from recent DFG purse seine sampling. No data are available from the summer tow-net survey for this area. Midwater trawl results for stations in Cache, Lindsey, and Barker sloughs indicate smelt are more abundant from October through December than in September, but they are not present in all years. Purse seine sampling was conducted in June and July 1993, but results are not yet available. A purse seine was used in March, April, and May 1992 in the Cache Slough area to collect delta smelt brood stock for development of fish culture methods for the species (Lindberg 1992). Adult smelt were collected during March, in mid-April, and again in early May.

Larval delta smelt have been monitored in Barker and Lindsey sloughs by DWR, DFG, and the University of California, Davis, since 1986 (except 1992), but were identified only to family in 1986 and 1987. In general, more larvae have been caught in Lindsey Slough than in Barker Slough (Table 4 and Figure 49).

Egg and larval survey data for 1988 to 1991 indicate larvae are present near the Barker Slough intake from March to early May and in Lindsey Slough near Cache Slough from March to June (Bennett 1992) (Figure 50).

Preliminary larval catch data for mid-February to mid-July 1993 indicate larvae were present from late March to late May on occasion in Barker Slough (March 29; April 26; May 2, 10, 20, 22) and more consistently in Lindsey Slough (March 25; April 2, 8, 18, 24, 28; May 2, 10, 12, 14, 16, 18, 26). The larvae in Barker Slough were 6-8 mm SL in March to early May and 14-16 mm SL in mid- to late May. In Lindsey Slough, larvae were 5-10 mm SL in March to mid-April and 8-12 mm SL in late April through May, with a few 5-6 mm SL larvae in mid-May (later spawning). Only 7 smelt were collected

Table 4
LARVAL DELTA SMELT CATCH IN
BARKER AND LINDSEY SLOUGHS NEAR THE
NORTH BAY AQUEDUCT, 1986 TO 1993
Pre-Project Years are 1986 to 1988
Smelt are Identified to Family Only in 1986 and 1987

Year	Lindsey Slough near Cache Slough Site 718	Site 719	Barker Slough near NBA Intake Site 720	Site 721	Total
1986	0	NS	0	1	1
1987	4	NS	0	2	6
1988	0	0	0	0	0
1989	5	5	0	0	10
1990	5	1	0	0	6
1991	9	2	3	3	17
1992	NS	NS	NS	NS	NS
1993	18	0	3	7	28
Total	41	8	6	13	68

NS No Sampling

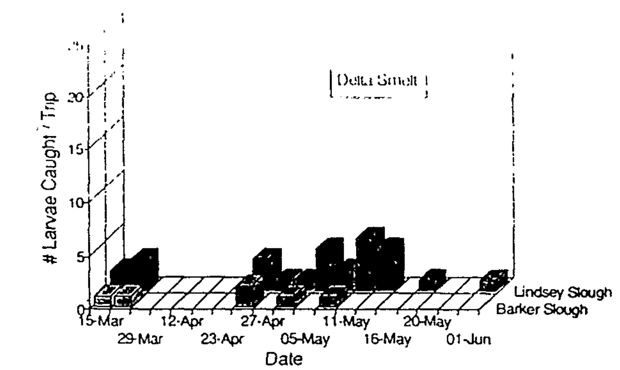

Figure 49
CATCH OF DELTA SMELT LARVAE IN
BARKER AND LINDSEY SLOUGHS
NEAR THE NORTH BAY AQUEDUCT, 1988 TO 1991
Source: Bennett 1992

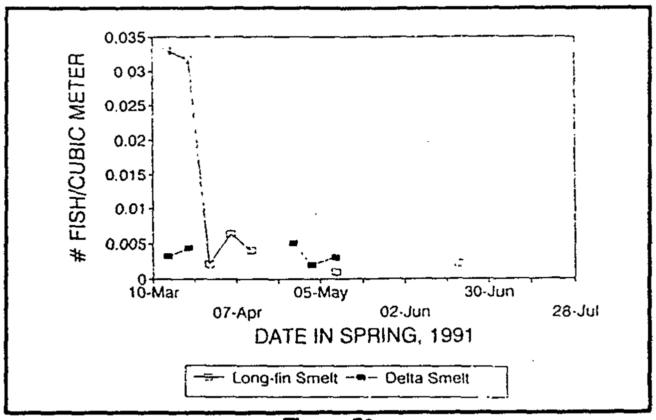

Figure 50
1991 SMELT DENSITY IN
BARKER AND LINDSEY SLOUGHS COMBINED
Source: Bennett 1992

near the Barker Slough intake in comparison to 20 smelt collected downstream in Lindsey Slough (Table 4). No larval smelt were collected after late May in either slough, but two juvenile delta smelt (21 and 25 mm SL) were collected with the egg and larval net in Barker Slough on June 21.

Bennett (1992) concluded that delta smelt larvae are rare and have a patchy distribution (time and space) in these sloughs, making entrainment estimates uncertain. However, an illustrative calculation of entrainment (based on larval striped bass densities in Barker Slough and potential water diversion rate per day) estimated delta smelt larvae could be entrained at a rate of 432 to 4,320 per day. Larval smelt entrainment has not been estimated using the same methodology as for the SWP and CVP intakes, and the degree to which it represents actual conditions is not known. That study also indicates abundance of striped bass larvae has increased significantly in Barker and Lindsey sloughs since project operations began. This could be due to water and larvae being drawn into the sloughs from the Sacramento River, where the striped bass densities are higher, or the area be used for spawning more in recent years because adults have been more concentrated in the lower Sacramento River.

Suisun Marsh Salinity Control Gates

A monitoring program was implemented in 1988 to assess effects of the Suisun Marsh Salinity Control Gates on fish and other aquatic resources in Suisun Marsh. This program includes existing sampling programs for *Neomysis* and zooplankton, egg and larval sampling, tow-net survey, juvenile salmon, and general fish population monitoring. A study of predators at the gates was added.

Monitoring results indicate minimal adverse impacts of the Montezuma Slough control gates on fish and other aquatic organisms in Suisun Marsh (Spaar 1992). While abundance and distribution of fish species, including delta smelt, have changed in the marsh, the changes are probably due to factors causing the general fisheries decline and to the 1987-1992 drought more than to control gate operations.

Delta smelt populations have declined in the marsh since 1981 (refer to Figure 2, on page 8). Otter trawls caught 423 delta smelt between 1980 and 1983 and only 13 in 1984 to 1992 (Meng *et al* 1992). Of these 13 smelt, 12 were collected in 1988 to 1992, after control gate operations began. Gate operations have resulted in relatively low salinities in the eastern marsh (upstream of Cutoff Slough) compared to higher salinities in the small sloughs of the western marsh. The delta smelt catch has been low but consistent since 1988, when gate operations began. In contrast, no delta smelt were caught in 3 of the 4 years immediately before the project. It is difficult to determine whether gate operations are causing marsh conditions to be more favorable for smelt.

Project impacts that could negatively affec delta smelt appear to be the increased catch o predatory fish (striped bass and squawfish) a the structure since 1987. However, no delt smelt were identified in predator stomach examined from 1987 to 1991.

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Another concern in this area is entrainment of delta smelt into Roaring River Slough and other private diversions within the marsh. During the 1980-1982 evaluation of the Roaring River fish screen, delta smelt was the most abundant fish collected at the unscreened diversion and was collected through both diversion seasons (November to May and September to March) (Pickard *et al* 1982). A total of 5,841 smelt were collected: 3,731 in 1980/1981 (66 mm average fork length; range 30-100 mm FL) and 2,110 smelt in 1981/1982 (average FL 63 mm; range 41-107 mm FL). Catches were usually higher for all species in samples taken at night. In September 1981 to March 1982, only 8 smelt were entrained under screened conditions (average FL 60 mm; range 25-74 mm) compared to 2,110 under unscreened conditions (average FL 66 mm; range 30-100 mm FL), demonstrating that the screen was extremely effective in reducing entrainment.

South Delta Temporary Barriers Project

The South Delta Temporary Barriers Project is designed to improve water levels, circulation patterns, and water quality in the southern Delta and to reduce impacts of Tracy and Banks Pumping Plants on fish, particularly salmon. Potential concerns for delta smelt include barrier impoundment, attraction, redistribution, and predator concentration.

Analysis of April-to-September salvage levels suggests that delta smelt entrainment did not increase while the barriers were in place (DWR 1993b). Egg and larval data show the barriers had little or no effect on distribution and recruitment of delta smelt larvae, given the extremely small number of larvae in the area and the timing of larval occurrence relative to barrier placement and operation. Fish and Game collected no delta smelt in monthly hoop-netting and electrofishing surveys upstream and downstream of the barriers, and found no delta smelt in the guts of predators sampled. Nonetheless, transport modeling studies suggest that entrainment of neutrally buoyant particles could increase under certain conditions when the barriers are in place. In particular, simulated entrainment of a tracer mass was shown to increase from 14.2 percent under the base condition (no barriers) to 20.8 percent at the Central Valley Project under a 3-barrier configuration (Old River near Tracy, Middle River, and Old River at Head). It is unclear why this increase would occur, because tracer concentrations did not change appreciably at any other export source when the barriers were in place. However, the modeled particles may move differently than delta smelt larvae, so these results must be interpreted with caution (DWR 1993b).

Pacific Gas & Electric Company

Pacific Gas and Electric Company operates two power generation facilities within the range of delta smelt: Contra Costa Power Plant and Pittsburg Power Plant. Contra Costa Power Plant is about 6 miles east of the confluence of the Sacramento and San Joaquin rivers. Pittsburg Power Plant is on the south shore of Suisun Bay, in the town of Pittsburg. Each power plant has seven generating units that rely on water diverted from the lower San Joaquin River and Suisun Bay for condenser cooling. Cooling water is diverted at a rate of up to about 1,500 cfs for the Contra Costa plant and 1,600 cfs for the Pittsburg Power Plant, forming a thermal plume as it is discharged back into the estuary. Pumping rates are often significantly lower under normal operation. Intakes at all units at both power plants employ a screening system to remove debris, but these screens allow entrainment of fish smaller than about 38 mm and impingement of larger fish.

Information on occurrence and direct entrainment of delta smelt near the PG&E power plants is limited because of taxonomic problems with earlier studies. Young delta smelt and longfin smelt are difficult to differentiate, so much of the early data is at the family (Osmeridae) level only. The available information suggests that larval and juvenile smelt, including delta smelt and longfin smelt, were historically one of the most abundant fish taxa in the area. In 1978 and 1979, Osmeridae was the most common group collected in ichthyoplankton samples near Pittsburgh Power Plant and the third most abundant near Contra Costa Power Plant (Ecological Analysts 1981a, 1981b).

There is also some specific evidence that juvenile and adult delta smelt have persisted in the project areas. Fishery surveys using a combination of gear types found that delta smelt comprised 1.8 percent of the catch of all species near Pittsburg Power Plant from August 1978 to July 1979 (Ecological Analysts 1981c) and 1.1 percent at discharge and reference sites from July 1991 to June 1992 (PG&E 1992a). Near Contra Costa Power Plant, delta smelt constituted only 0.1 percent of the catch in 1978 and 1979 (Ecological Analysts 1981d) but 0.7 percent in 1991 and 1992 (PG&E 1992a). However, results from the summer tow-net survey (see Chapter 3) at stations closest to Pittsburgh Power Plant indicate abundance has declined since the peak levels in the mid-1970s. As shown in Figure 51, the mean catch of delta smelt declined in the 1980s at stations 520 and 508, located upstream and downstream of Pittsburg Power Plant. At station 804, near Contra Costa Power Plant, mean catch of delta smelt has been consistently low except in 1965 and 1973 to 1977.

PG&E has conducted extensive monitoring at both power plants. Early general monitoring was followed by studies emphasizing larval and juvenile striped bass. Entrainment estimates for smelt are available from 1978 and 1979 only, and larval data are limited because of difficulties in differentiating longfin smelt and delta smelt. PG&E (1981a, 1981b) reports that from April 1978 to August 1979, more than 50 million smelt larvae (Osmeridae) were entrained at Pittsburg Power Plant and an additional 11,000 juvenile delta smelt impinged on the screens. Entrainment was similarly high at Contra Costa Power Plant for Osmeridae larvae (16 million) and juvenile delta smelt (6,400). An important consideration in evaluating these data is that larvae entrained in cooling systems are not necessarily lost. Survival rates of entrained striped bass and other species can be high, but the effects on delta smelt are not known. Smelt do not

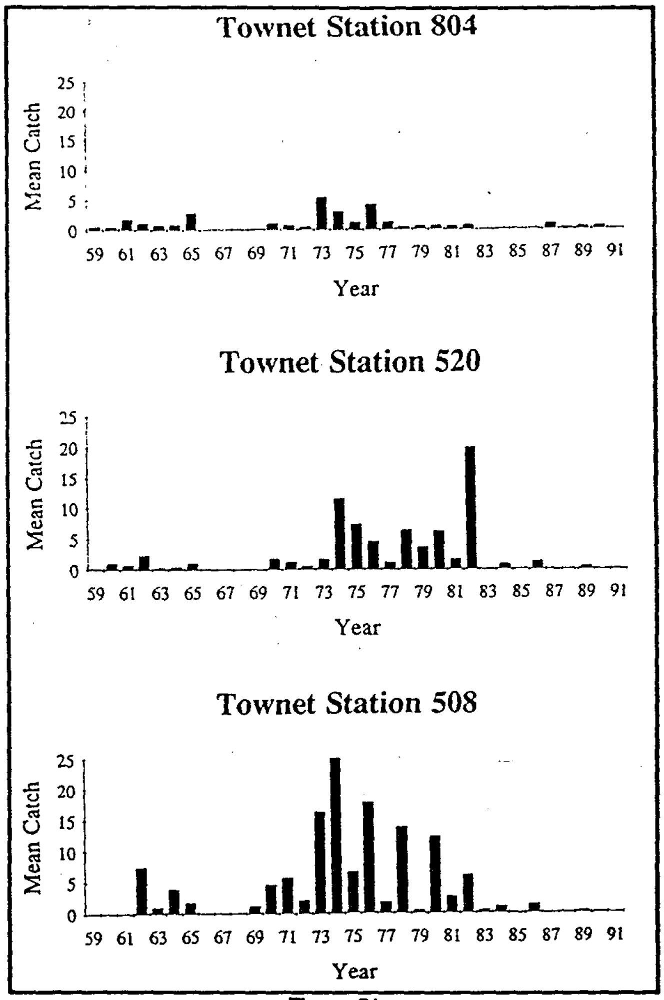

Figure 51
MEAN CATCH PER TOW OF DELTA SMELT AT SUMMER TOW-NET SURVEY STATIONS NEAR PITTSBURG POWER PLANT AND CONTRA COSTA POWER PLANT
Station 804 is near Pittsburg Power Plant;
Stations 520 and 508 are near Contra Costa Power Plant

appear to tolerate stress, as indicated by low survival following trucking and handling during CVP and SWP salvage operations.

Survey results from nearby summer tow-net stations suggest many of the larvae entrained in the 1978-1979 studies were delta smelt. Longfin smelt are rarely caught at Station 804, near Contra Costa Power Plant, and were not observed in 1978 and 1979. This compares to low but detectable levels (mean catch 0.5) of delta smelt. Delta smelt also outnumbered longfin smelt during 1978 and 1979 at Station 520 (mean catch 5.0 delta smelt, 0.4 longfin smelt) just upstream of the Pittsburg plant and Station 508 (mean catch 7.1 delta smelt, 0.4 longfin smelt) just downstream of the Pittsburg plant. A limitation in interpreting these results is that the summer tow-net survey was conducted after the period of peak entrainment, so the species composition may not be strictly comparable.

Thermal effects may result in direct mortality, behavioral attraction, avoidance, blockage, or increased predation. This issue is discussed in a recent report by PG&E (1992b). The study found greater numbers of some fish species near thermal discharge sites, but no evidence for direct mortality of striped bass and no thermal blockage of migratory species, including Chinook salmon, striped bass, and American shad. Insufficient numbers of delta smelt were collected to draw any conclusions about how they are affected by the thermal discharges. Predation on juvenile Chinook salmon and larval striped bass suffering thermal stress may be higher in Contra Costa Units 6 and 7 discharge canal, but the report concluded the effect is probably minimal. The overall effect of thermal discharges on delta smelt is not known, but sampling indicates there is no behavioral attraction.

Since the 1978-1979 studies were completed, PG&E has implemented a resource management program to reduce striped bass loss. During the period of peak striped bass e[...]ment (May to mid-July), power gene[...] units are operated preferentially, using monitoring data. This program has re[...] entrainment losses of larval and ju[...] striped bass by more than 75 percent (PC 1992a). The revised operations may [...] incidental benefits to delta smelt, bu[...] cannot be estimated because there is prese[...] no monitoring requirement for this spec[...]

Local Agricultural Diversions

Larval, juvenile, and adult delta smelt are v[...]nerable to entrainment into Delta agricu[...] diversions, a potential risk for the popul[...] Diversions in the northern and central De[...] where smelt abundance is highest, are like[...] greatest problem. An estimated monthly av[...] of 2,000 to 5,000 cubic feet per second is diver[...] during the peak irrigation period (April-Au[...] from about 1,850 diversions scattered throu[...]out the Delta (Brown 1982). This is the sa[...] order of magnitude as is exported by the [...] and CVP in the southern Delta.

In 1992, the Department of Water Resou[...] initiated the Delta Agricultural Diversion Eva[...]ation to assess the extent to which delta sm[...] and other species are lost to these diversi[...] Sampling was conducted from mid-April throu[...] October 1992 and began again in late A[...] 1993. In general, 1992 results seem to s[...] that some larval species (*eg*, threadfin sha[...] centrarchids) are more vulnerable to entr[...]ment than others (*eg*, striped bass, chame[...] goby, prickly sculpin) relative to their abundan[...] in the adjacent Delta channel.

Larval fish also appeared to be more vulne[...]able than other life stages. Based on the ini[...] analysis of data from the 1992 pilot stu[...] entrainment appears to depend largely on th[...] species in question, its life stage, seasonal ab[...]dance and distribution in the adjacent chan[...]

(including location in the water column), and operations of the diversion (seasonal timing, length of diversion, and volume) (Spaar 1993b). Many diversions do not operate continuously and divert water only for a few days to a few weeks at a time.

During 1992 sampling, no larval, juvenile, or adult delta smelt were collected from the four diversions sampled (Spaar 1993b) (Figure 52). In this pilot year, however, sampling methods for juvenile and older fish were found to be inefficient. In addition, the Twitchell Island diversion off the San Joaquin River, an area of known delta smelt abundance, could not be sampled.

Larval smelt were collected in April and May by egg and larval sampling in the Delta channels adjacent to the Twitchell Island, Bacon Island, and McDonald Island sites (Table 5). Larval smelt abundance in these catches was generally low, and catches were infrequent in comparison to most other larval species caught,

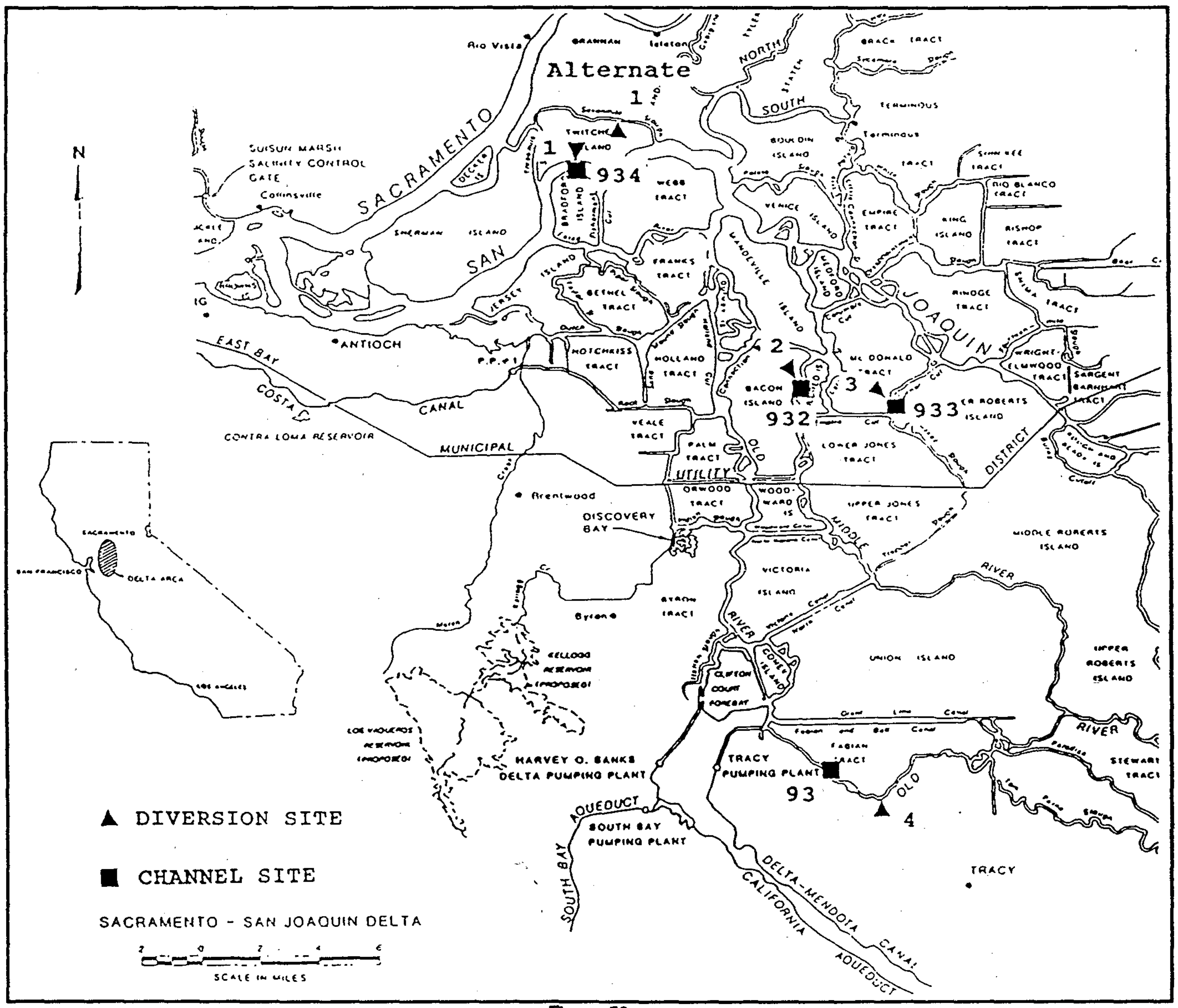

Figure 52

DIVERSIONS AND ADJACENT CHANNEL SITES SAMPLED FOR THE 1992 PILOT STUDY OF DELTA AGRICULTURAL DIVERSIONS

Site numbers refer to those on Table 5.

Table 5
TOTAL CATCH, BY SPECIES, OF LARVAL FISH COLLECTED DURING THE DELTA AGRICULTURAL DIVERSION EVALUATION, APRIL TO OCTOBER 1992
Number per 10,000 Acre-Feet

	Diversion Sites				Channel Sites			
Species	1 Twitchell Island*	2 Bacon Island	3 McDonald Island	4 Naglee-Burk	934 Twitchell Island*	932 Bacon Island	933 McDonald Island	93 Naglee-Burk
Chameleon goby	—	161.76	214.67	32.99	447.91	407.79	1650.76	282.37
Threadfin shad	9.14	99.41	337.01	82.04	50.01	48.28	123.11	49.98
Prickly sculpin	—	1.24	—	—	55.25	38.82	40.53	85.09
Striped bass	—	10.92	—	—	625.55	36.24	3.80	1.32
Centrarchids	9.61	18.13	1.36	7.33	0.86	1.08	1.51	1.70
Bigscale logperch	—	2.16	—	0.77	1.73	2.79	4.66	2.18
Inland silverside	46.21	—	—	—	—	—	—	0.80
American shad	—	3.59	—	—	—	—	—	—
Cyprinids	—	1.11	—	1.77	5.51	0.80	1.54	0.17
Delta smelt	—	—	—	—	2.74	0.80	0.39	—
Sacramento splittail	—	—	—	—	0.21	—	—	0.15
Sacramento sucker	—	—	—	4.67	—	0.41	—	—
Mosquitofish	—	—	0.41	—	—	—	—	0.06
Ictalurids	—	—	—	—	—	—	—	0.04
Yellowfin goby	—	—	—	—	1.13	—	—	—

*An alternative diversion site was sampled was on Sevenmile Slough. Channel site was on the San Joaquin River.

such as chameleon goby, threadfin shad, and striped bass. No larval smelt were collected near the Naglee Burk site in the southern Delta.

Although most of the 1993 larval samples are still being processed in the laboratory, preliminary data are available for April to June from both egg and larval and juvenile nets. Sampling methodology and juvenile nets were modified for 1993 to increase sampling efficiency. Preliminary results indicate two larval delta smelt (15 mm total length) were collected from two 1-hour samples in late morning at the Bacon Island siphon on May 17, 1993. The diversion flow was about 12.5 cfs, and catches per unit effort were 0.92 and 0.89 larvae per acre-foot of water diverted. These fish were collected from the live-box of the juvenile net (1/8-inch mesh), which covered the siphon outfall. A few days later, a 48-hour study on May 19 to 21 did not collect any life stages of delta smelt, even though larval fish of other species were caught (striped bass, threadfin shad, logperch, gobies).

No juvenile or adult delta smelt have been collected from the diversions. Also, no larval smelt have been collected using the egg and larval net (505-micron mesh) in the diversion. However, channel egg and larval sampling has collected larvae adjacent to the Bacon Island and Twitchell Island diversion sites in March through early June 1993. Diversions at these sample sites started later in 1993 than in 1992 due to the heavy rainfall from fall 1992 through spring 1993, which delayed the onset of irrigation diversions (late April at Bacon and late May at Naglee-Burk).

In general, delta smelt are probably most vulnerable to entrainment from February through June, during their larval and early juvenile stages. Swimming ability is weakest in the larval stage for most fish species. The irrigation season runs generally from late March or early April through September (Brown 1982), but varies from year to year depending on the weather, crop, and other factors. Diversions are minimal during December through February. Winter irrigation is usually for wheat or other grains and, in a drought year, for permanent crops (orchards, vineyards). The agricultural diversions now being studied often do not begin operations until late April or May. Some diversions are often operated intermittently during the irrigation season. Four of the five sample sites monitored in 1993 divert intermittently, including all irrigation diversions for Bouldin Island. Potentially, the period of highest losses of delta smelt to agricultural diversions would be April through June, based on their life stages at this time and timing of the irrigation season.

Predation and Competition

Other factors that may control the abundance of delta smelt are predation and competition from native and introduced fish species and introduced invertebrates. The available evidence is reviewed below.

Predation

Balanced relationships between predator and prey populations may be disturbed by perturbations in their environment. Fish stocks are continually subjected to predation of fluctuating intensity, with the surplus prey becoming the established population; predator/prey populations are usually in dynamic equilibrium (Bagenal 1978). When a newly introduced predator begins to consume a prey population that has been in equilibrium with its competitors and other predators, the initial effect is an increase in the mortality rate of the prey. If stocks are declining and fish are unaccountably disappearing, the decline may be due to new predators or some perturbation that has favored native or introduced predators.

Although the assemblage of native fishes in this estuary evolved together, some disturbance could favor native predators, such as Sacramento squawfish, steelhead, and Sacramento perch. This seems unlikely, however, because none of these is presently abundant in the estuary (Stevens *et al* 1990).

One change in the estuarine environment that could have favored native or introduced predators was increased water transparency in many regions of the upper estuary over the last 20 years (see "Water Quality", later in this chapter). Increased water transparency could render delta smelt more susceptible to predation. Correlation analyses suggest delta smelt abundance in several regions of the upper estuary declined significantly with increasing water transparency during various seasons and was most significant in winter and spring. However, this does not prove cause-and-effect; it only suggests a relationship between delta smelt abundance and water transparency. Water transparency may affect year class strength during the first half of each year; that is, increases in water transparency may adversely affect delta smelt during the period when year class strength is thought to be set. Comparisons between summer tow-net indices and fall midwater trawl indices suggest smelt year class strength is set before July (Stevens *et al* 1990).

Predation by introduced fish species is another possibility, although several of these species have also declined in abundance during the same period as delta smelt (Stevens *et al* 1990). Catfish and sunfish are predatory fish but were established in this estuary well before the decline of delta smelt. Striped bass has been the most abundant predator in the estuarine area inhabited by delta smelt (Stevens *et al* 1990) but has been present in the Delta for more than a hundred years. Previously, much larger populations of both striped bass and delta smelt coexisted (Sweetnam and Stevens 1993). Food habit studies in the 1960s, when both species were abundant, indicate that, although occasionally consumed, delta smelt were not a major prey item for striped bass. The planting of large numbers of juvenile striped bass near Rio Vista, an area where delta smelt have concentrated in recent years, probably affects smelt to some degree through increased predation. This issue is presently moot, because DFG discontinued stocking hatchery-produced striped bass in the estuary in 1992 due to concerns regarding predation on young winter-run salmon (Sweetnam and Stevens 1993).

The most likely predation factor in the delta smelt decline is that a recently introduced species may be responsible. Introduced species colonize rapidly under favorable conditions and may disrupt the structure of fish communities by competing with or preying on native fishes (Herbold and Moyle 1986). The species likely to have the greatest effect are the inland silverside (introduced in 1975) and the yellowfin and chameleon gobies (both introduced in the late 1950s). Chameleon gobies are not a likely suspect, since they have been abundant in the upper estuary and Delta only since the mid- to late 1980s. However, they may limit recovery of delta smelt populations.

Inland silverside, which could prey on delta smelt eggs and larvae, has been collected where delta smelt are spawning (Moyle *et al* 1993), but its measured abundance has been highly variable (Sweetnam and Stevens 1993). Bennett and Moyle (1993) described research to be conducted at the University of California, Davis, to investigate competition and predation of inland silverside as co-factors with outflow as the cause of the dramatic declines in delta smelt abundance. They suspect such a situation between silverside and smelt in the estuary for several reasons.

Silverside abundance increased dramatically in the early 1980s, concurrent with the smelt decline (Bennett and Moyle 1993) (Figure 53). Silverside co-occurs in high abundance with smelt eggs and larvae. Recent predation experiments using large field enclosures in this estuary (Bennett *et al* 1993) indicate that inland silversides readily consume striped bass larvae (5-8mm SL), producing higher daily mortality rates than those reported in similar experiments using larval fish prey and small fish predators (Fuiman and Gamble 1988; Pepin *et al* 1992; and Cowan and Houde 1993, cited by

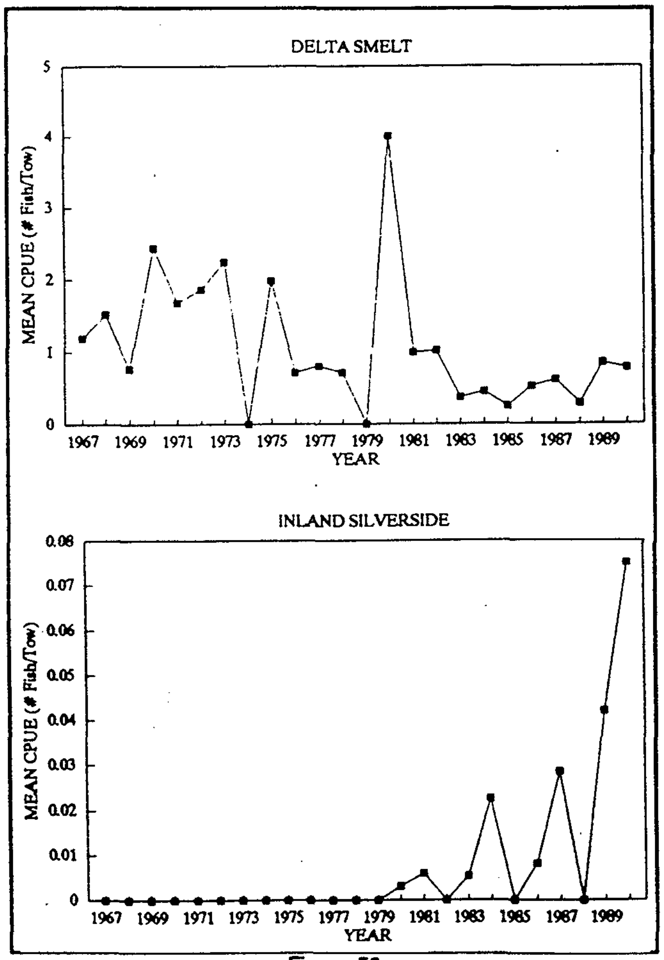

Figure 53
MEAN CATCH PER TOW OF
DELTA SMELT AND INLAND SILVERSIDE IN THE
FALL MIDWATER TRAWL SURVEY, 1967 TO 1990

Bennett and Moyle 1993). Prey selection was also found to be size-based. Therefore, since smelt larvae are of similar size as those striped bass larvae used by Bennett *et al* (1993), they would also be consumed if encountered. Finally, low outflow may exacerbate predation on larval smelt by concentrating the spawning smelt in areas of high silverside abundance in the Delta.

Yellowfin and chameleon gobies could also prey on delta smelt eggs and young. Although generally not thought of as predators, gobies are small, bottom-dwelling carnivores of inshore areas that exhibit a lie-in-wait feeding behavior (McGinnis 1984). Yellowfin gobies are larger than the native marine gobies. Both species feed on invertebrates and small fish. In general, gobies are able to adapt to low salinities and to habitats not accessible to other fishes. In the Delta, chameleon goby appears to have a long spawning season, with larval stages collected from early April through mid-September (Spaar 1993). The young are zooplankton feeders until they reach 1-2 cm, at which time they assume their bottom predatory role. Gobies also are known to consume fish eggs (Jude *et al* 1992).

Due to the bottom-dwelling, inshore nature of yellowfin and chameleon gobies, juveniles and adults are fairly successful in avoiding midwater tow-nets and trawl nets and generally appear to be low in abundance in these types of samples. However, goby larvae are susceptible to egg and larval nets, and juveniles and adults appear to be susceptible to otter trawls, which sample on the bottom. Results from egg and larval sampling in the southern Delta indicate that chameleon goby abundance increased tremendously, from comprising 2 percent (291 larvae, 0.95 larvae/tow) of the 1988 catch to its peak of 87 percent (137,455 larvae, 584.91 larvae/tow) of the 1991 catch (Spaar 1990; Spaar 1992). While abundance declined to 83,293 larvae (61 percent of total catch, 259.48 larvae/tow) in 1992, it is still the most abundant larval species caught at this study's central and southern Delta sites. Although sampling began in mid-February in 1991 and 1992, no chameleon goby were caught before April, as in other years. The tremendous numbers of larvae alone being produced would indicate this species could have a large impact on the estuarine ecosystem.

An ongoing, 14-year otter trawl survey in Suisun Marsh, done for the Department of Water Resources by the University of California, Davis, found that abundance of both yellowfin and chameleon goby has fluctuated dramatically in recent years, whereas other species have declined steadily (Meng *et al* 1993) (Figure 54).

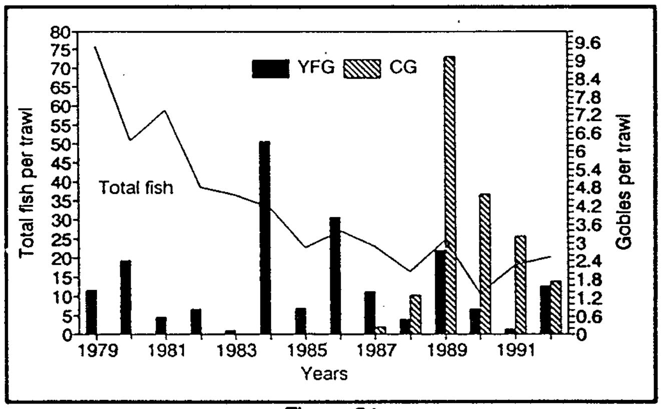

Figure 54
ABUNDANCE OF
CHAMELEON GOBY, YELLOWFIN GOBY, AND TOTAL FISH
IN SUISUN MARSH, 1979 TO 1992
Source: Meng *et al* 1993.

Native species, including delta smelt, were found more often in small, dead-end sloughs; introduced species (particularly chameleon goby) were found both in dead-end sloughs and the larger sloughs of the marsh. Yellowfin goby increased dramatically throughout the estuary in the late 1960s and early 1970s (Britton *et al* 1970), and was the third most abundant fish caught in the marsh in 1980 through 1982. Its abundance in the marsh has fluctuated since that time (Figure 54), but it has remained one of the more abundant species (fourth in 1991 and third in 1992). Chameleon goby did not follow this pattern; it was first caught in the marsh in 1985 and by 1989 it was the most abundant fish caught. Recently, its numbers have declined, as might be expected for an introduced species. These changes in fish abundance in the marsh suggest introduced species, along with other environmental disturbances, have altered fish communities and hastened fish declines.

Competition

Effects of competition among species are difficult to determine. Introduced fish and invertebrate species may compete directly with delta smelt (adults and young) for food (phytoplankton and zooplankton) or may alter the species composition of the zooplankton community. The zooplankton food niche was originally divided between the native delta and longfin smelts (McGinnis 1984). Delta smelt occupies the fresher, upstream areas of the estuary, and longfin smelt occupies the more saline, lower reaches. The natural niche segregation between these species has been influenced by the introduction of exotic zooplankton feeders, which could compete with delta smelt for food resources. Although zooplankton food supply has improved in recent years (see next section, "Food Abundance"), this does not preclude the possibility that some form of competition, such as food depletion, could affect delta smelt.

Several introduced fish species could compete with delta smelt for food. Young striped bass, American shad, threadfin shad, inland silverside, chameleon goby, and wakasagi are all zooplankton feeders and probably compete with delta smelt for food. Striped bass has shown signs of population decline coinciding with or preceding the decline of delta smelt.

Inland silverside has been shown to be a successful colonizer and competitor with native or established species (Mense 1967; Li *et al* 1976; Bengston 1985). In Lake Texoma, Oklahoma, inland silverside completely replaced brook silverside in about 2 years after its introduction (Mense 1967). As adults, delta smelt and inland silverside are of similar size and have overlapping diet requirements, thus they may compete if shared food resources are limited (Bennett and Moyle 1993). In the Bay/Delta system, low food abundance and changing composition suggest food may be limiting for larvae as well as adults (Moyle *et al* 1992). Bennett and Moyle (1993) are investigating potential competition of inland silverside with delta smelt. Silversides form dense schools in shoal areas, whereas smelt are more abundant in river channels; this does suggest some degree of habitat segregation. However, they theorize that considerable overlap may occur between the species at prime feeding times. In Clear Lake, silversides are known to undertake diel inshore-offshore feeding migrations. Such behavior may produce locally depressed food resources for delta smelt at favored feeding sites and times, increasing the probability of resource competition.

Competition for food at the larval stage may also be increasing due to an unexplained population explosion of the chameleon goby in 1990 (Sweetnam and Stevens 1993). Wakasagi may also compete with delta smelt for food in the upper end of the delta smelt's range on the Sacramento River, but no research has been done on this.

The Asian clam, *Potamocorbula amurensis*, was first discovered in Suisun Bay in 1986. It may compete directly with delta smelt for food by consuming *Eurytemora affinis*[1] nauplii.

1 This copepod is a primary food of delta smelt.

P. amurensis has been implicated as the cause for the sharp decline of *E. affinis* in late 1988 (Kimmerer 1992a). It may also impact phytoplankton dynamics by decreasing phytoplankton biomass, thereby affecting higher trophic levels. However, *P. amurensis* occurs primarily downstream of Antioch, which has been the extreme lower range for delta smelt in recent years, so their overlap has probably been minimal. Overlap may increase in wetter years, such as 1993, unless distribution of the clam shifts downstream in such years. *P. amurenis* will likely be a continued problem for this region, as recent U.S. Geological Survey results show the clam was not significantly displaced downstream by high flows in 1993 (Jan Thompson, USGS, unpublished data).

Food Abundance

Changes in the concentration of either phytoplankton or zooplankton could affect delta smelt abundance through food chain interactions. Exact food requirements of delta smelt are not known, but prey densities in the Bay/Delta appear low relative to other systems in the United States, creating the potential for food limitation (Miller 1991).

Recent trends in concentration and composition of phytoplankton and zooplankton are described below in relation to delta smelt. It is important to note that food chain effects may be closely linked with entrapment zone position. Both phytoplankton and *E. affinis* have been shown to occur at peak abundances within the entrapment zone (Kimmerer 1992a). Although the abundance of each is also correlated to some degree with entrapment zone location, the mechanism for this association is unknown. The correlations may be due to underlying relationships with flow, strength of entrapment, or other factors that vary with entrapment zone position (Kimmerer 1992a; Jassby 1993). The possible importance of the entrapment zone is described at the beginning of this chapter.

Phytoplankton Trends

Phytoplankton levels were analyzed by removing the effects of specific conductance and season, which cause short-term and localized variation. "Anomalies" were calculated by subtracting pigment[1] measurements for each date and station from the mean pigment value for the specific conductance class (Table 6) and month. A positive anomaly indicates pigment levels were higher than would be expected for the respective month and specific conductance class. The use of anomalies is described in detail by Obrebski *et al* (1992).

Table 6
AVERAGE SPECIFIC CONDUCTANCE AND SALINITY IN SPECIFIC CONDUCTANCE CLASSES 1 TO 20
Specific conductance values shown are referenced to a standard temperature, but change at different temperatures.

Class	Specific Conductance (µS/cm*)	Salinity (ppt)
1	126	0.071
2	150	0.084
3	167	0.094
4	187	0.105
5	210	0.118
6	240	0.135
7	284	0.159
8	355	0.199
9	473	0.265
10	674	0.378
11	979	0.550
12	1554	0.874
13	2511	1.417
14	3934	2.229
15	5817	3.313
16	8032	4.604
17	10583	6.112
18	13665	7.964
19	17444	10.284
20	24302	14.635

* µS/cm = microSiemens per centimeter
** ppt = parts per thousand

1 Pigment is an indicator of phytoplankton levels.

Over the last 20 years, a significant decline in phytoplankton biomass has been observed ($P<0.01$) in the region between Rio Vista on the Sacramento River and Martinez at the west end of Suisun Bay (Figure 55). Chlorophyll *a* concentrations declined sharply between 1972 and 1977, followed by increased levels between 1978 and 1982 and then another decline from

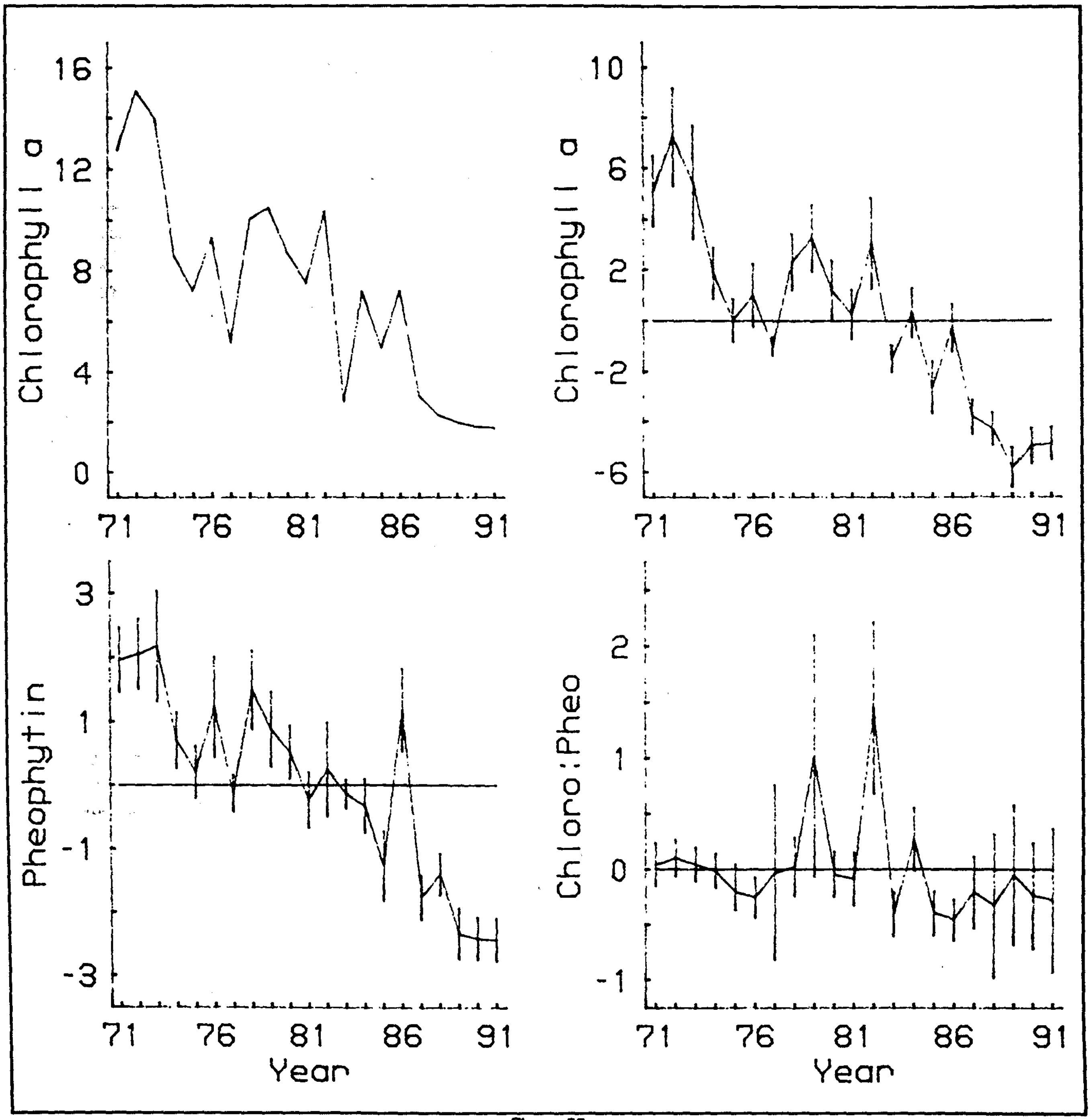

Figure 55
PIGMENT CONCENTRATIONS, RIO VISTA TO MARTINEZ, 1971 TO 1991
The upper left graph is mean annual concentration, in µg/L.
All other graphs are mean annual anomalies (described in text), with 95 percent confidence intervals.
Horizontal lines mark zero anomaly value.

1983 through 1991. Mean annual chlorophyll *a* concentrations have been extremely low (<4 μg/L) since 1987. Seasonal and annual variation in phytoplankton is hypothesized to result from transport from outflow and interactions with benthic grazers (Alpine and Cloern 1992). Trends in phaeophytin *a* levels were similar to those for chlorophyll *a*. Ratios of chlorophyll *a* to phaeophytin *a* hovered around zero during most years, although unexplained spikes in chlorophyll *a* occurred in 1979 and 1982. These results suggest the relationship between phytoplankton growth and mortality has been consistent in this region. However, this analysis does not reflect localized changes within regions of the Delta or shifts in species composition.

It appears that phytoplankton abundance may affect delta smelt directly, as well as through the zooplankton food chain. In laboratory culturing of delta smelt, Mager (1993) found that larvae first began feeding on day 4 (after hatch) on phytoplankton and on day 6 were feeding on rotifers. Prior to this, there has been no mention of phytoplankton as a food item for delta smelt in any reports or papers. The period of first feeding for larval fish is generally thought to be a critical time for larval survival.

Zooplankton Trends

Studies indicate copepods are the principal prey item of delta smelt, but a shift in species composition has occurred. Post larval smelt collected in 1977 were found to feed almost exclusively on copepods (Moyle *et al* 1992). Gut analysis showed that the calanoid copepod, *Eurytemora affinis* was the dominant prey item (68% by volume), followed by *Cyclops* sp. (31%) and harpacticoid copepods (1%). Adult smelt were found to feed throughout the year on copepods and seasonally on cladocerans (*Daphnia* sp., *Bosmina longirostris*) (Moyle *et al* 1992). Opossum shrimp (*Neomysis mercedis*) was generally of secondary importance. By contrast, the main food item in 1988 samples was *Pseudodiaptomus forbesi*, an exotic species. *Sinocalanus doerii*, another exotic species, has also been found in gut samples, as have *Corophium* sp., Gammaridae, and Chironmidae (Moyle *et al* 1992).

Zooplankton data were examined using anomaly values, described in the foregoing section, to examine long-term trends. Trends for *E. affinis*, the most important prey item in the 1970s, show abundance of this copepod has declined significantly in the area between Rio Vista and Martinez during the last 18 years (Figure 56). The decline was gradual but continuous between 1972 and 1983, followed by a brief period of stable abundances, and ending in a major decline between 1987 and 1990.

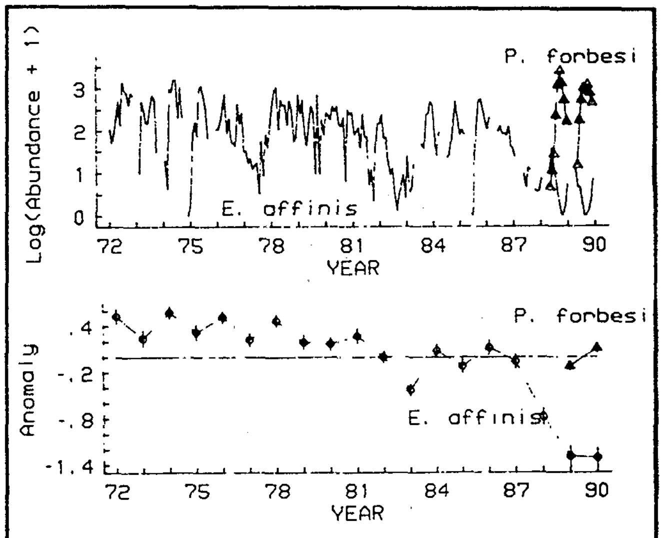

Figure 56
ZOOPLANKTON CONCENTRATIONS,
RIO VISTA TO MARTINEZ, 1972 TO 1990
Top graph is mean monthly log abundance of zooplankton from all sites sampled.
Bottom graph is mean annual anomalies (described in text),
with 95 percent confidence intervals.

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The exotic clam *Potamocorbula amurensis* is thought to be at least partly responsible for the most recent decline of *E. affinis*. This clam was well established in Suisun Bay by 1987 and, with its efficient feeding habits, has managed to consume a significant portion of the phytoplankton biomass in Suisun Bay (Alpine and Cloern 1992) and possibly a significant number of juvenile *E. affinis* (Kimmerer 1992a).

The introduced zooplankton *Pseudodiaptomus forbesi* was discovered in this estuary in 1987 (Orsi and Walter 1991). By fall 1988, this copepod was found in high concentrations (>1000 m^{-3}) in many regions of the upper estuary. Diet studies of delta smelt completed in 1988 and 1991 show this organism is now the main food source of delta smelt. Abundances of *P. forbesi* in 1989 and 1990 were equal to those of *E. affinis* prior to its precipitous decline in the late 1980s (Figure 56). Thus, while abundance of *E. affinis* remains low, total food supply for delta smelt appears to have increased in recent years. Herbold *et al* (1992) made similar conclusions about delta smelt food availability.

Water Quality

Few water quality factors have the potential to affect the abundance and distribution of delta smelt over its entire range. Water temperature, water transparency, and specific conductance (salinity) are the water quality parameters that could most likely affect population levels, given the environmental changes within the estuary. Constituents such as pH and dissolved oxygen have not changed on a scale large enough to affect a mobile organism such as delta smelt, and chemicals such as silica, nitrate, and phosphate are not thought to directly affect delta smelt.

This section discusses the potential for water temperature, water transparency, and specific conductance to affect the delta smelt population. Data for many of the analyses were partitioned among various regions of the upper estuary (Figure 57) to permit a more detailed examination. Results should be interpreted with caution, however, because there is evidence of serial autocorrelation problems with the tow-net and midwater trawl data. This concern is discussed in the section "Entrapment Zone" earlier in this chapter.

Water Temperature

In this estuary, water temperature is regulated mainly by air temperature, but river inflow and tidal intrusions also influence estuarine water temperatures. Long-term trends in surface water temperature show a highly seasonal pattern that is consistent among years and regions (Figure 58). Water temperatures are lowest during winter and highest during summer.

The predictable pattern of water temperature contributes directly to many of the seasonal changes noted throughout the estuary. Water temperature outside the optimal range for delta smelt could alter growth and mortality rates of this fish.

Water temperatures during delta smelt spawning reportedly range from 7 to 15 degrees C (Wang 1986). However, water temperatures measured during high larval abundance (April to June) typically range from 15 to 23 degrees C (DFG 1992). The ability of delta smelt to survive higher temperatures is supported by Moyle *et al* (1992), who found delta smelt in waters ranging from 6 to 23 degrees C and averaging 15 degrees C.

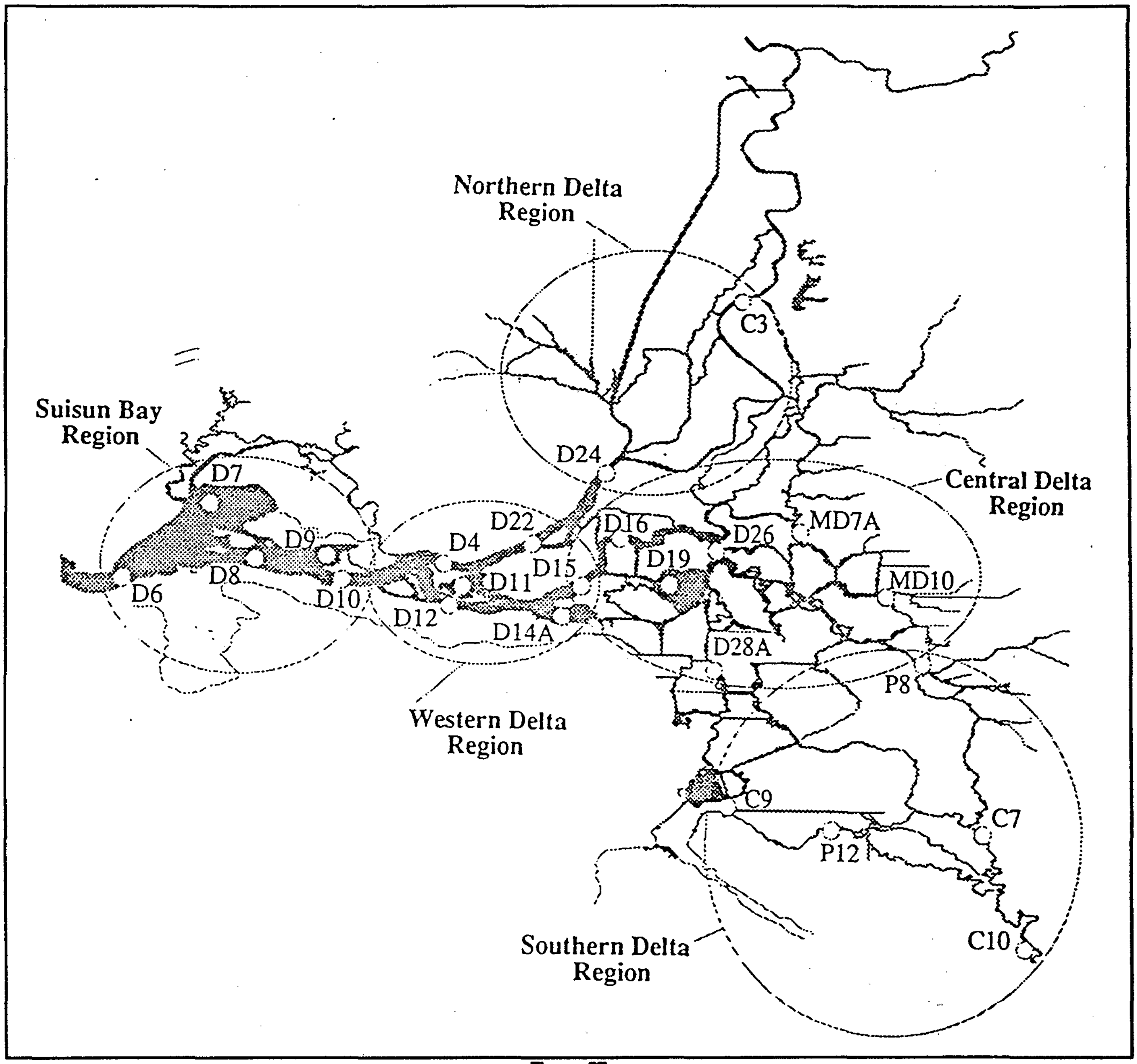

Figure 57

LOCATION OF CORE DATASET SITES AND REGIONS USED IN WATER QUALITY ANALYSES

For these analyses, Site D15 was considered part of the western Delta only.

Site C10 was not included in the Secchi disc depth analysis because this constituent was not measured at this site after 1982.

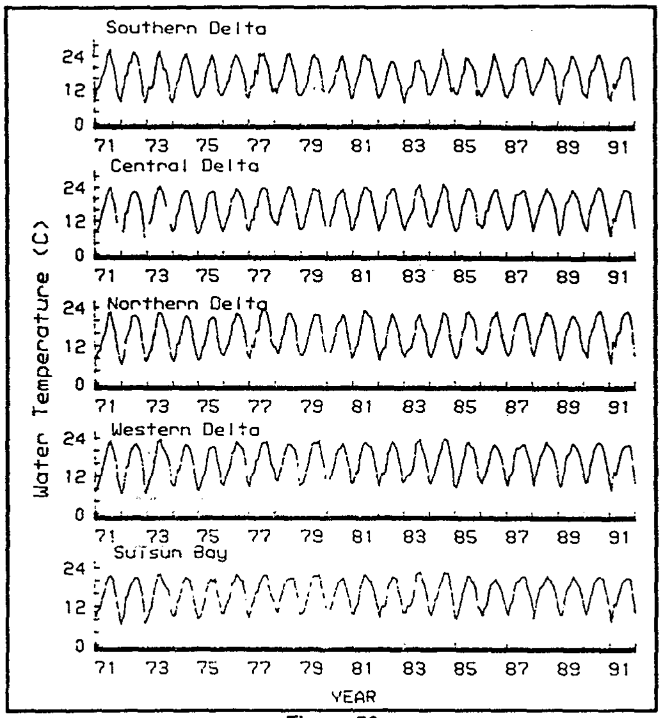

Figure 58
MEAN MONTHLY WATER TEMPERATURE
FOR FIVE REGIONS IN THE UPPER ESTUARY, 1971 TO 1991

Long-term water temperature trends in the upper estuary show little or no pattern that could account for a decline in delta smelt abundance or a change in distribution. Lehman and Smith (1991) noted a slight increase in average monthly temperatures in the late 1970s, before most delta smelt abundance indices began to decline. Minor temperature changes could have caused a delayed response through the food chain or other mechanisms. However, Stevens *et al* (1990) found no relationship (by regression analysis) between water temperature and smelt abundance. During the last 20 years, water temperatures in all regions of the upper estuary have only occasionally been outside an assumed delta smelt tolerance range of 7 to 15 degrees C between December and March and 15 to 23 degrees C between April and June (Figure 58). Thus, the analyses suggest water temperature has not affected delta smelt abundance and distribution.

Water Transparency

Water transparency varies in direct proportion to the concentration of suspended organic and inorganic particles. The major source of inorganic material is suspended sediments brought in with streamflows. This is a highly seasonal component that increases with runoff and flow. The two major forms of organic matter are particulate organic material and phytoplankton. This component is also seasonal; phytoplankton concentrations tend to be highest during spring through fall, while particulate organic material is probably highest during fall and winter.

Although any change in water transparency could affect delta smelt, increases in water clarity that are probably of most concern. Increased water transparency may render delta smelt more susceptible to predation or decrease food availability, as many zooplankton are negatively phototactic.

Secchi disc depth readings show water transparency has varied greatly within and among years throughout the upper estuary but suggest an increasing trend in some regions (Figure 59).

Further analysis involving removal of the variation in Secchi disc depth due to season and salinity (anomaly calculations, described earlier) shows water transparency has increased significantly (slope of regression line >0; P<0.001) in all regions of the upper estuary except Suisun Bay (Figure 60).

Stevens *et al* (1990) found a strong relationship between fall delta smelt abundance and July-October copepod abundance and water transparency. However, they considered this relationship tentative because the strong connection between summer tow-net indices and fall midwater trawl indices suggests smelt year-class strength is set before July.

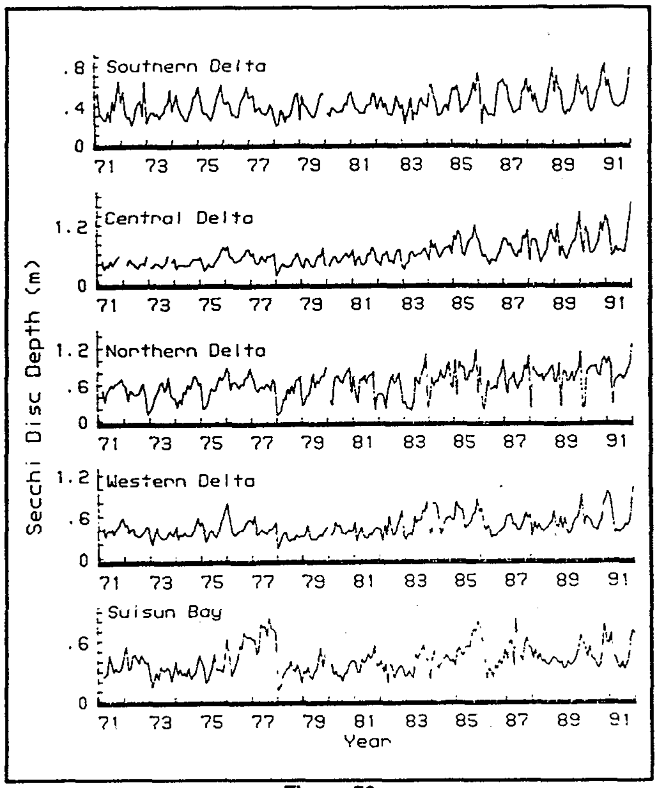

Figure 59
MEAN MONTHLY SECCHI DISC DEPTH
FOR FIVE REGIONS IN THE UPPER ESTUARY, 1971 TO 1991

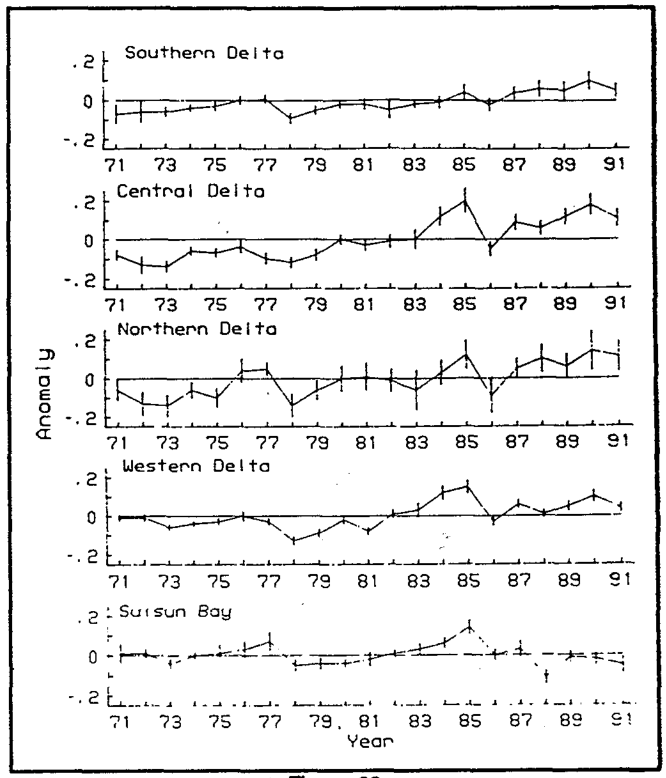

Figure 60
SECCHI DISC DEPTH ANOMALIES
FOR FIVE REGIONS IN THE UPPER ESTUARY, 1971 TO 1991
Values are annual mean anomalies, with 95 percent confidence intervals.

Tests results for relationships involving various water quality and biological constituents can be misleading because most chemical and biological constituents vary with salinity. Delta smelt are no exception, having a definite abundance pattern over the salinity range common to the upper estuary (Figure 61). Thus, significant relationships between two constituents could occur because of covariation with salinity, when in fact there is little or no direct relationship between the two.

We have evaluated the relationship between water transparency and delta smelt abundance further with a somewhat different analytical approach from that used by Stevens *et al* (1990). First, the upper estuary was divided into five geographic regions (Figure 61). This increases the sensitivity of the analysis, because water transparency readings are not summed between regions that could be governed by different processes. Second, seasonal Secchi disc depth anomalies were calculated for each region. Anomalies were calculated to remove the effects of salinity from Secchi disc depth trends and, therefore, the covariation between water transparency and delta smelt abundance due to salinity. The anomalies were then correlated with an appropriate measure of abundance (tow-net index, midwater trawl index, or salvage), depending on the season and region, summarized in Table 7.

Results show delta smelt abundance is negatively correlated with water transparency. In addition, these correlations suggest delta smelt abundance in several regions declined significantly with increasing water transparency during various seasons. The relationship between delta smelt abundance and water

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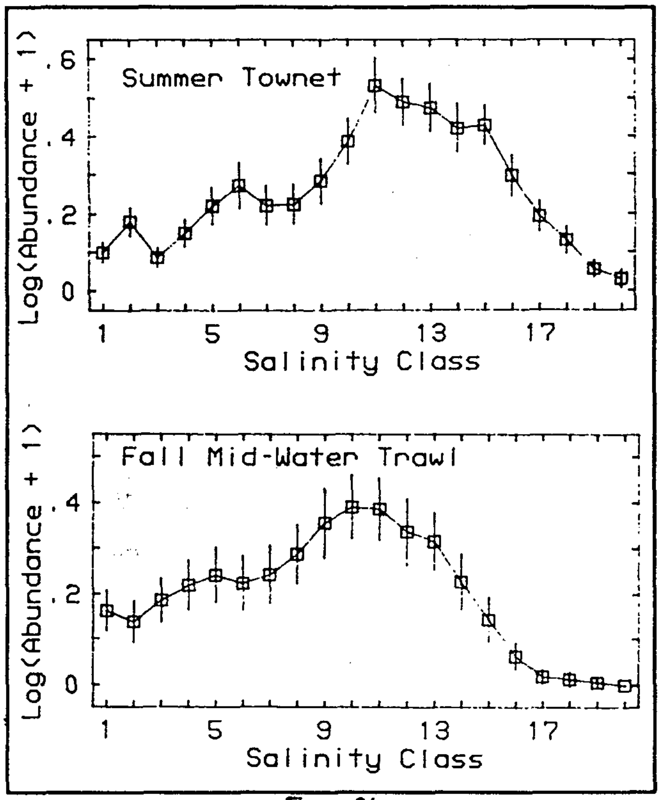

Figure 61
DELTA SMELT ABUNDANCE VERSUS SALINITY CLASS
All values are mean log base 10 abundance, with 95 percent confidence intervals. Salinity classes are summarized in Table 6.

transparency was most often significant in tow-net analyses for winter and spring. This suggests water transparency has the greatest effect on year-class strength during the first half of each year; that is, increases in water transparency may adversely affect larval and juvenile smelt during the time when DFG believes year-class strength is set (Stevens *et al* 1990).

Although these results suggest delta smelt abundance may be inversely related to the increasing trend in water transparency, they do not prove cause and effect. Moreover, autocorrelation problems could detract from reliability of the results. Studies designed specifically to test this relationship are needed before a definitive conclusion can be reached.

Table 7
RESULTS OF CORRELATION ANALYSES BETWEEN DELTA SMELT ABUNDANCE[1] AND MEAN SEASONAL ESTIMATES OF SECCHI DISC DEPTH AND SPECIFIC CONDUCTANCE FOR FIVE REGIONS IN THE UPPER ESTUARY
Constituent values are mean seasonal specific conductance and mean seasonal Secchi disc depth anomalies (variation due to specific conductance removed).
All results are for 1971 through 1991, except the salvage data, which are for 1976 through 1991.

	Correlation Coefficients			
Constituent	Winter	Spring	Summer	Fall
Southern Delta				
Secchi Disc Depth	-0.70***	-0.42*	-0.02	-0.45*
Specific Conductance	0.33	-0.02	0.17	0.04
Secchi Disc Depth[2]	-0.67**	0.13	0.05	-0.02
Specific Conductance[2]	-0.02	0.27	0.31	0.55**
Central Delta				
Secchi Disc Depth	-0.58**	-0.64***	-0.40*	-0.27
Specific Conductance	-0.10	0.08	-0.07	-0.25
Northern Delta				
Secchi Disc Depth	-0.30	-0.29	-0.36*	-0.39*
Specific Conductance	-0.05	0.11	-0.002	-0.14
Western Delta				
Secchi Disc Depth	-0.51**	-0.59**	-0.33	-0.09
Specific Conductance	-0.09	-0.12	0.10	-0.25
Suisun Bay				
Secchi Disc Depth	-0.46*	-0.16	-0.24	-0.07
Specific Conductance	-0.15	-0.003	-0.10	-0.19

* $P < 0.05$
** $P \leq 0.01$
*** $P < 0.005$
1 The summer tow-net abundance index was used in winter and spring correlations. The midwater trawl abundance index was used in summer and fall correlations. Abundance of delta smelt salvaged at the State Water Project was also correlated with the water quality constituents in the southern Delta region.
2 Constituent correlated with mean seasonal abundance of delta smelt salvaged at the State Water Project.

Specific Conductance

In this estuary, variations in specific conductance are driven primarily by the movement of salt water. The southern Delta region is a notable exception. Agricultural drainage water can comprise a substantial portion of the water volume in this area, thereby altering specific conductance independent of salt water movement. Specific conductance also varies with temperature, so values are usually referenced to a single temperature level. Numerous chemical and biological constituents are correlated with specific conductance, a measurement from which salinity can be determined (Millero 1984). Changes in specific conductance affect the ability of delta smelt to regulate their body fluids, and exposure to water outside its optimal salinity range are physiologically stressful.

Specific conductance directly affects distribution of delta smelt, which appears to have an optimal salinity range above or below which abundances decline (Figure 61). Tow-net and midwater trawl catches indicate delta smelt are most abundant between 800 and 7700 µS/cm (0.45 and 4.4 ppt). This is consistent with Moyle *et al* (1992), who found delta smelt in salinities from 0 to 14 ppt, with a mean value of 2 ppt.

Long-term trends show specific conductance has varied substantially within and among regions of the upper estuary over the last 20 years (Figure 62). In all regions, specific conductance was highest during drought periods (1976-1977 and 1987-1991) and lowest during wet periods (1975 and 1983). However, even with the large variation and lengthy drought periods, specific conductance has not exceeded the upper end of the salinity range in which smelt are most abundant (7700 µS/cm) in three of five regions examined. In Suisun Bay, specific conductance has exceeded the salinity range for delta smelt almost every year between 1971 and 1991, and since 1983 specific conductance has remained above 7700 µS/cm for extended periods. In the western Delta, specific conductance has exceeded the salinity range for delta smelt only during five drought years (1976, 1977, 1987, 1988, 1990).

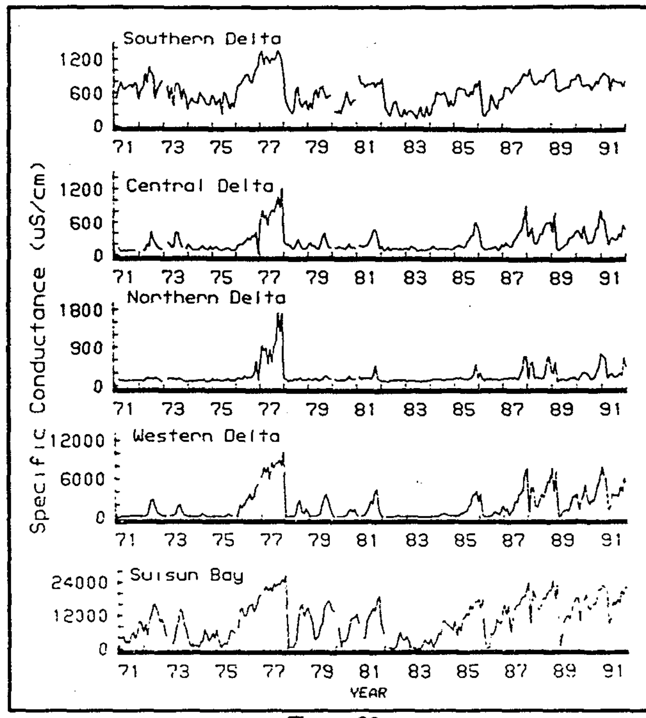

Figure 62
MEAN MONTHLY SPECIFIC CONDUCTANCE
FOR FIVE REGIONS IN THE UPPER ESTUARY, 1971 TO 1991

Because specific conductance has such a major influence on the estuarine environment, further analyses were conducted to explore the possibility of a relationship between salinity and delta smelt abundance and distribution. Mean seasonal specific conductance values were correlated with appropriate measures of delta smelt abundance on a regional basis, summarized in Table 7. Although one significant relationship was found, most results showed no significant relationship between seasonal specific conductance and delta smelt abundance. These results are consistent with the interpretation of long-term specific conductance data, which show substantial variation, primarily within the salinity range of delta smelt except in Suisun Bay.

No long-term relationship between delta smelt abundance and specific conductance in Suisun Bay is evident, but the major decline in delta smelt and the most substantial increases in specific conductance did not occur until after 1983. Correlations between delta smelt abundance and mean seasonal specific conductance in Suisun Bay between 1984 and 1991 show a significant relationship only for spring (r=-0.70; P< 0.05). This analysis suggests delta smelt may have been affected by the higher springtime (April to June) specific conductance levels in Suisun Bay after 1983.

Catches of delta smelt have also declined in Suisun Marsh. As with many other measures of delta smelt abundance, the turning point was 1983, after which only four delta smelt have been caught (Moyle *et al* 1992). Since 1983, monthly salinity values in the Suisun Marsh sampling region have exceeded the upper salinity range (4.4 ppt) where delta smelt are most abundant 36 percent of the time; between 1979 and 1982, monthly salinity values exceeded the upper range 20 percent of the time. Although these results suggest increased salinity levels could be limiting the distribution of delta smelt in Suisun Marsh, both salinity and smelt abundance have varied in this region (Figure 63). In fact, the increased variability in salinity may be limiting the occurrence of delta smelt in Suisun Marsh rather than the incidence of salinity values in excess of its salinity range. However, these results do suggest salinity levels and/or variability in Suisun Marsh may be adversely affecting delta smelt in this region.

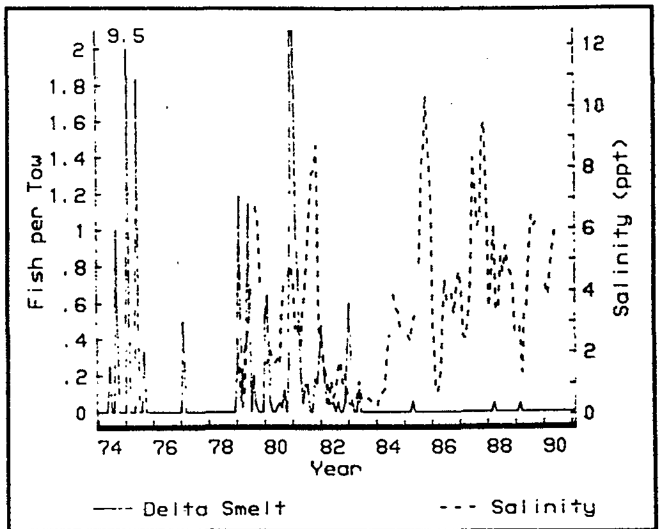

Figure 63
MEAN MONTHLY CATCH OF DELTA SMELT AND AVERAGE MONTHLY SALINITY IN SUISUN MARSH, 1974 TO 1990

Contaminants

Toxic contaminants have been identified as a factor that could affect delta smelt survival (USFWS 1991). Possible pollutants include heavy metals, pesticides, herbicides, and polycyclic aromatic hydrocarbons. Although contaminants in the water column are probably the greatest threat to delta smelt, sediment interactions are also a concern. There is good evidence that pollutants in sediments may have significant effects on the biota of the benthic environment, even at low levels (Elder 1988).

Delta smelt eggs attach to rocks, gravel, or vegetation (Moyle 1976). Where these substrates contact sediments, interactions with contaminants are possible. Delta smelt larvae are generally pelagic rather than benthic (Moyle 1976), but they may also be at risk because significant numbers of larval and juvenile delta smelt have been observed near the bottom (Randy Baxter, DFG, unpublished data; Randy Mager, University of California, Davis, unpublished data; also see "Agricultural Diversions" earlier.

in this chapter). Finally, there is evidence that disease occurs more frequently in fish larvae that contact toxic materials on the bottom in marine environments (Mearns, cited by Moyle and Cech 1988).

No toxicity studies have been conducted to verify the degree to which pollutants in water and sediments affect delta smelt. Available information is limited to monitoring of toxic compounds in the Delta and studies on other species.

Monitoring of Contaminants

Concentrations of 9 trace metals and 39 chlorinated organic pesticides in the water column are measured biannually at 11 sites in the Delta and Suisun Bay. A report on Delta water quality during 1990 shows that the concentration of trace metals has decreased or remained the same since 1987, except for total iron concentration, which increased somewhat in 1990 (Department of Water Resources 1992b). Between 1987 and 1990, organic pesticides were rarely found at concentrations above the minimum reporting limit. However, heavily localized or pulse events are rarely detected by the biannual survey. U.S. Geological Survey monitoring has found that volumes of agricultural water discharged into the Sacramento and San Joaquin rivers may persist as a toxic pulse through the Delta (Kuivila *et al* 1992, 1993; Meyers *et al* 1992). Compounds measured included molinate, carbofuran, thiobencarb, and diazinon, which were present at levels in excess of U.S. Environmental Protection Agency maximum criteria for aquatic life. Foe and Sheipline (1993) provide additional evidence that orchard and alfalfa pesticide runoff from the Central Valley often occurs at toxic levels.

San Francisco Regional Water Quality Control Board studies found cadmium, copper, chromium, nickel, lead, zinc, and mercury in sediments from Grizzly Bay and the Sacramento River within the range of delta smelt. These sediments have been found to be toxic to invertebrates in April, when larvae and young delta smelt occur in the system (Taberski *et al* 1992). Even if pollutants in the sediments do not directly affect delta smelt eggs or larvae, studies on heavy metal accumulation in waterfowl of San Francisco Bay (Ohlendorf *et al* 1986) and selenium accumulation in Suisun Bay (White *et al* 1989) demonstrate that impacts through the food chain are a threat.

Effects of Contaminants on Fish Species

No toxicity studies have been conducted on delta smelt, but there is evidence of problems for related species and other Delta fish. A 1978 study examined the effects of pollution on smelt populations (*Osmerus eperlanus*) in the lower River Elbe, Germany (Kohler and Holzel 1980). The river system was characterized by high levels of heavy metal pollution, pesticides, and polychlorinated biphenyls. In the study, smelt captured in the polluted Elbe showed severe liver problems compared to those from unpolluted areas in the North Sea.

Toxic substances have also been implicated in the mortality of striped bass at different life stages and may have played a role in their decline (Foe and Connor 1991). During the mid-1970s, increased applications of rice pesticides resulted in a sevenfold increase in toxic contamination in the Sacramento River flowing into the Delta. Bioassays showed that drain water entering the Sacramento River was toxic to striped bass larvae (Foe 1988, 1989). Foe (1989) also developed a correlation model, which showed that application rate of the rice pesticide methyl parathion accounted for a statistically significant portion of the variance in the young-of-the-year striped bass index.

The toxicity of agricultural discharges is supported by studies of the Colusa Basin Drain by the University of California, Davis (Bailey 1992). Drain water was found to be toxic to striped bass larvae for three consecutive seasons of study (1989 to 1991). The study also found a significant portion of the annual variation in striped bass recruitment from 1973 to 1988 could be accounted for by the level of rice pesticide used. However, evidence also suggests that toxicity may have been reduced in 1991 and 1992 after a practice of holding irrigation water on fields throughout the growing season was implemented.

Studies of striped bass kills provide more evidence of possible toxicity problems. In May and June each year, up to hundreds or thousands of dead adult bass are in the estuary, particularly in Carquinez Strait. In 1985, researchers from the University of California, Berkeley, discovered that moribund striped bass collected in a die-off showed liver disease disfunction, a possible indication of chronic problems from toxins (Brown *et al* 1987). This hypothesis is supported by Cashman *et al* (1992), who found that livers from moribund striped bass were greatly contaminated by chemicals compared to those from healthy fish caught in the Delta and Pacific Ocean. Contaminants included a variety of industrial, agricultural, and urban pollutants, and no one causative agent could be identified.

Other evidence of toxic contamination comes from D. Hinton and W. Bennett of the University of California, Davis. Liver sections of striped bass larvae from the Sacramento River show much higher incidence of malformation than larvae from elsewhere. About 26 percent of the larvae they sampled in the Delta in 1988 and 1989 exhibited liver abnormalities characteristic of exposure to toxic chemicals. However, no quantitative estimates of mortality were made (Bennett *et al* 1990). Liver histology studies have been funded by the Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary to determine whether toxins are a significant problem for delta smelt (Sweetnam 1992).

Finally, research from the San Joaquin River basin indicates subsurface agricultural drain water may be toxic to juvenile fish. Saiki *et al* (1992) demonstrated that water samples collected from an agricultural drain south of the Delta could cause mortality of juvenile Chinook salmon and striped bass. Although the samples were collected considerably upstream of delta smelt spawning areas, drain water may comprise a significant portion of the streamflow in the San Joaquin River during the irrigation season.

Disease and Parasites

Potential impacts from disease and parasites on fish range from relatively mild impairment of health to mortality. No doubt a relatively small percentage of infections are known, and for these the knowledge is incomplete. A major concern is that widespread introductions of pathogens have occurred through discharge of ballast waters from ships, intentional introductions for specific purposes, and the ornamental or aquatic pet trade (Stewart 1991). Given the large number of exotic fish and invertebrates introduced into this estuary (Hymanson 1992), new pathogens have likely entered the system, but there is little evidence as to whether disease or parasites significantly affect the abundance of delta smelt or impede species recovery. The limited observations are discussed in the following sections.

Disease

In some years, disease is thought to cause widespread mortality of carp and white catfish in the estuary, but mortality of delta smelt has not been specifically observed (Stevens *et al* 1990). Continuing studies by the University of California, Davis, may help to resolve this issue. In particular, recent attempts to culture delta smelt have been hampered by several parasitic and bacterial infections. The most serious problem is *Mycobacterium*, a genus of bacteria known to cause chronic infections in fish and other species. The disease appears to be the major cause of delta smelt mortality in the laboratory, and it may cause deaths among wild fish as well.

The Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary is funding studies by the University of California, Davis, that include estimation of the incidence of infection among wild populations and evaluation of water temperature effects on bacterial infections (Hendrick 1993).

Parasites

Information about parasites is limited to general studies on other Delta species. Edwards and Nahhas (1968) and Hensley and Nahhas (1975) found that many types of protozoans, trematodes cestodes, nematodes, and crustaceans infect at least 28 species of Delta fish. The Department of Fish and Game (1989) also reports that striped bass in the Delta are more heavily infested with parasites than those on the Atlantic coast, indicating that the Delta fish may be more susceptible to infection (possibly because of greater environmental degradation from toxicants and pollutants) or that the species has poor defenses against endemic parasites.

Interbreeding with Wakasagi (Pond Smelt)

Under the assumption that delta smelt and wakasagi were the same species, wakasagi was introduced in 1959 from Japan into several California lakes and reservoirs as a forage fish for trout (Wales 1962). Wakasagi are present in Folsom Lake and have been collected in the American River downstream of the lake and close to the Delta (Moyle *et al* 1993).

Sweetnam and Stevens (1993) suggested that the possibility of genetic dilution of delta smelt by wakasagi has increased due to immigration of wakasagi from Central Valley reservoirs to the estuary.

Delta smelt and wakasagi must be able to interbreed if genetic dilution is to occur. Results from recent electrophoretic studies confirm that delta smelt and wakasagi are distinct species, and there is as yet no indication of hybridization (Stanely *et al* 1993). Delta smelt is more closely related to surf smelt (*H. pretiosus*) than to wakasagi. The distant relationship between delta smelt and wakasagi reduces the likelihood of successful hybridization between the two taxa. If a hybrid did form, it would probably be sterile (P. Moyle, pers comm).

Based on this work, it does not appear that genetic dilution through interbreeding with wakasagi is a significant threat to the delta smelt population.

Spawning Stock Size and Year-Class Strength

Examination of year-class strength as a potential factor controlling delta smelt abundance is based on the stock-recruitment theory. Year-class strength is the measure of recruitment, or the numbers of young alive at some future time that were produced by the adult stock. The stock-recruitment relationship defines the stock's ability to replenish itself as stock size is reduced by exploitation (Koslow 1992).

In general, attempts to relate recruitment in fish and other populations to parent stock size have been largely unsuccessful on an empirical level (Hankin 1980). The lack of definable stock-recruitment relationships is a consequence of the early life history strategy of fish, high fecundity and high mortality rates. Given that mortality is an exponential process, small deviations in mortality lead to large changes in survivorship, which may obscure the SR relationship (Koslow 1992). Therefore, recruitment may appear to be not related to adult stock size or only weakly and linearly related to stock size, except when spawning stock is exceptionally high or low.

Due to the 1-year life cycle of delta smelt, adult smelt abundance may be limited by abundance and, consequently, egg production of adults in the previous year. The stock-recruitment relationship for this species has been examined in Stevens *et al* (1990), Moyle *et al* (1992), Kimmerer (1992b), and most recently by Sweetnam and Stevens (1993).

These analyses differed in the types of abundance index used, the years analyzed, and the types of statistical analysis (Table 8). Analysis by Stevens *et al* (1990) using midwater trawl data, which was also presented in Moyle *et al* (1992), inadvertently included two pairs of

Table 8
SUMMARY OF STOCK-RECRUITMENT ANALYSES FOR DELTA SMELT
Level of significance tested not given unless noted.

Analysis	Type of Analysis	Index	Years	r^2	N
Stevens *et al* (1990)	Nonlinear Regression	Tow-Net	1959-1990	0.067	26
	Nonlinear	Tow-Net/Fall Midwater Trawl	1968-1988	0.096	18
	Nonlinear	Fall Midwater Trawl	1967-1989	0.236	19
Moyle et al (1992)	Not Stated	Fall Midwater Trawl	1967-1989	0.24	19
Kimmerer (1992)	Linear Regression	Composite[1]	1959-1991	0.79**	32
	Linear	Fall Midwater Trawl	1967-1991	0.392**	20
Sweetnam & Stevens (1993)	Nonlinear	Fall Midwater Trawl	1967-1992	0.23	21
	Linear	Fall Midwater Trawl	1967-1992	0.24	21
Department of Water Resources	Nonlinear	Fall Midwater Trawl	1967-1991	0.32**	20
	Linear	Fall Midwater Trawl	1967-1991	0.392**	20
	Nonlinear	Fall Midwater Trawl	1967-1992	0.227*	21
	Linear	Fall Midwater Trawl	1967-1992	0.266*	21
	Spearman Rank Correlation Test	Fall Midwater Trawl	1967-1992	r=0.62**	21

* $p < 0.05$
** $p < 0.01$
1 Composite index was calculated as the first principal component of three indices: tow-net, midwater trawl, and SWP salvage. To fill data gaps, multiple regression was used, which included indices not missing for that year and the previous year's composite index.

SR data in which the measure of recruitment occurred 2 years later than the stock measurement. This may have affected results, given the 1-year lifespan for most delta smelt. The Department of Fish and Game updated this analysis using corrected data points and recently revised midwater trawl indices through 1992 (Sweetnam and Stevens 1993), superseding the earlier efforts.

Analysis of the stock-recruitment relationship for this assessment reviewed the analyses of midwater trawl data by Kimmerer (1992b) and Sweetnam and Stevens (1993). The SR relationship using the midwater trawl data in Table 9 was examined using nonlinear regression (Beverton-Holt SR model), linear regression and log transformation techniques, and nonparametric statistics.

Table 9
FALL MIDWATER TRAWL ABUNDANCE INDICES
USED IN STOCK-RECRUITMENT ANALYSIS
(Data from Department of Fish and Game)

Year*	Stock	Recruitment
1968	415	697
1969	697	316
1970	316	1678
1971	1678	1305
1972	1305	1267
1973	1267	1146
1976	698	338
1977	338	480
1978	483	572
1981	1651	375
1982	375	346
1983	346	132
1984	132	182
1985	182	109
1986	109	212
1987	212	280
1988	280	126
1989	126	366
1990	366	363
1991	363	689
1992	689	157

* Year recruitment was measured. No stock abundance data were available for recruitment years 1967, 1975, and 1980, which are not included in this analysis.

One of the statistical methods used to examine the stock-recruitment relationship was the Beverton-Holt stock-recruitment model through nonlinear regression techniques. Stevens *et al* (1990) analyzed the SR relationship using the striped bass summer tow-net data for 1959 to 1990, a combination of summer tow-net and fall midwater trawl data, and the midwater trawl data for 1967 to 1989 (Figure 64). They found a weak SR relationship for all three datasets, but no indication was given whether the relationship was significant or not. The best SR relationship could account for one-fourth (r^2=0.236, N=19) of the variability in recruitment abundance based on midwater trawl data only.

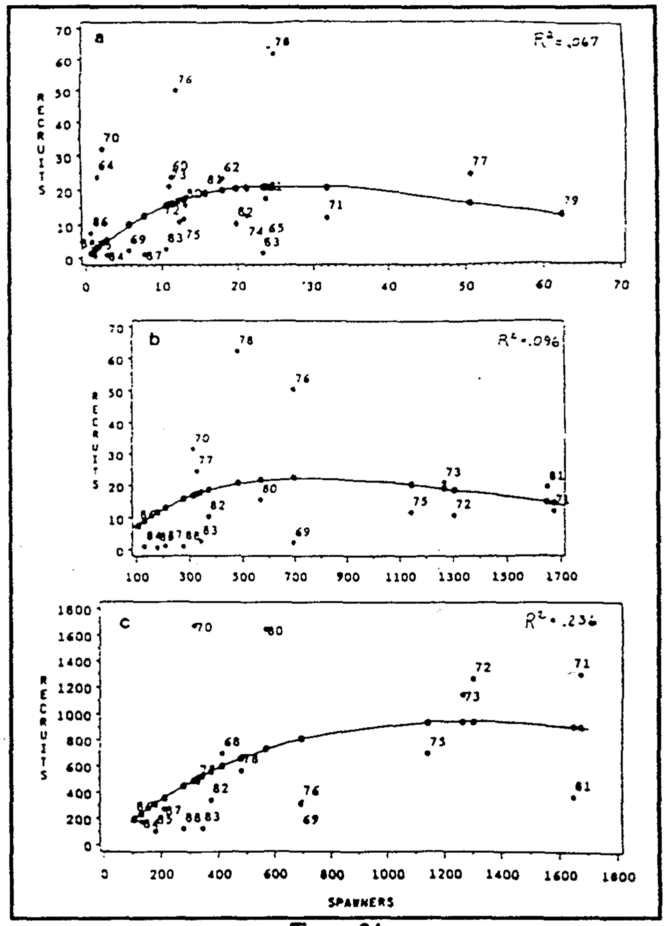

Figure 64
SPAWNER-RECRUIT RELATIONSHIPS FOR DELTA SMELT
A. Tow-net index (spawners) and tow-net index for the following years (recruits).
B. Midwater trawl index (spawners) and tow-net index the following year (recruits).
C. Midwater trawl index (spawners) and midwater trawl index the following year (recruits).
Source: Stevens *et al* 1990.

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More recent examinations of the relationship based on midwater trawl data again found spawning stock accounted for about one-fourth of the variability (r^2=0.23, N=21) in Sweetnam and Stevens (1993) (Figure 65) and in our analysis ($p<0.05$, r^2=0.229, N=21) (Table 8).

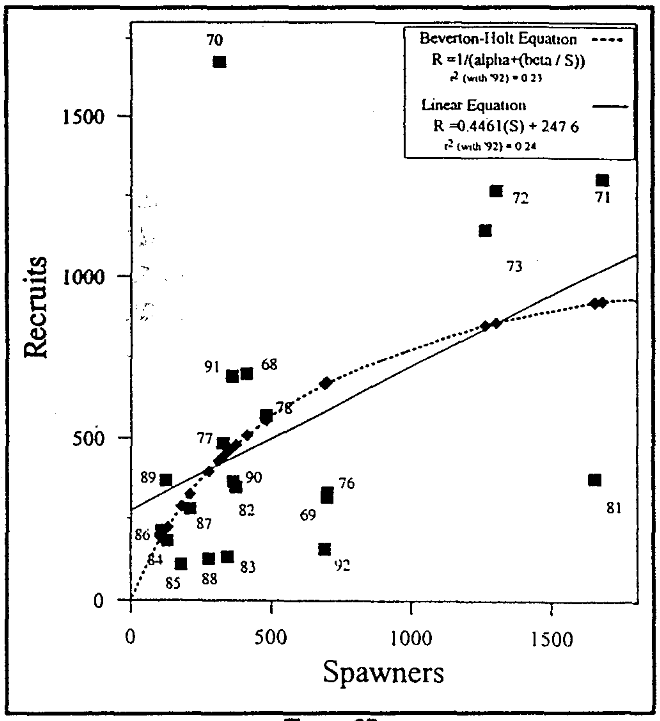

Figure 65
SPAWNER-RECRUIT RELATIONSHIPS FOR DELTA SMELT BASED ON THE FALL MIDWATER TRAWL ABUNDANCE INDEX
Spawners are represented by the abundance index.
Recruits are represented by the abundance index for the following year.
Source: Sweetnam and Stevens 1993.

The strength of the relationship still suggests factors other than stock size (*ie*, environmental) are limiting delta smelt abundance, but stock size is still a contributing factor. Sweetnam and Stevens (1993) indicated that spawning stock size may be more important than previously thought, in that losses of adult spawners may have played an important role in the delta smelt decline and may inhibit recovery.

Another statistical method used was linear regression and both log transformed and untransformed datasets. Kimmerer (1992b) found a significant relationship between recruitment and parent stock size for delta smelt based on his composite index of summer tow-net, fall midwater trawl, and State Water Project salvage operation data and to a lesser extent based on the midwater trawl abundance indices (Figure 66).

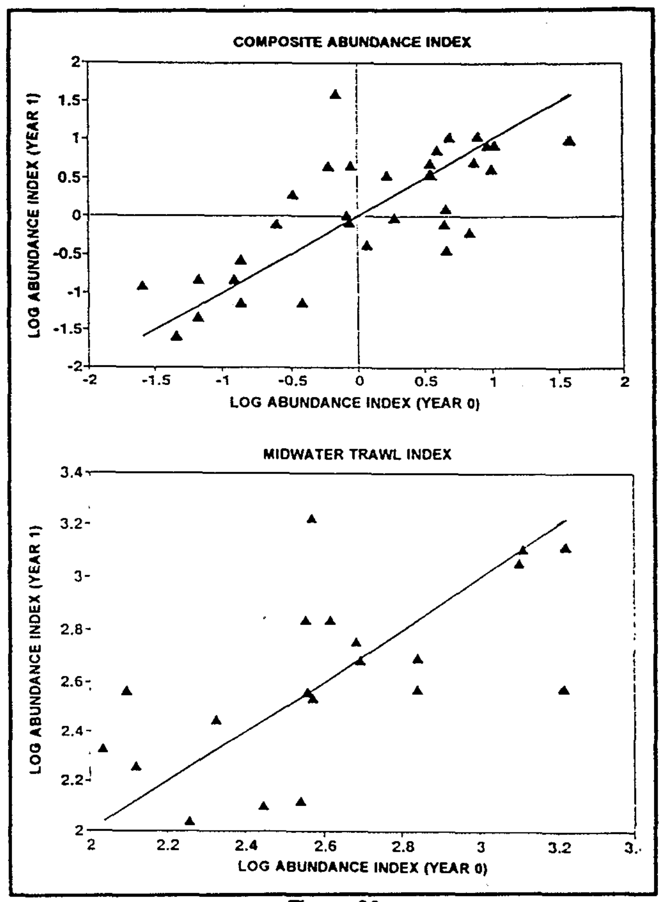

Figure 66
DELTA SMELT STOCK-RECRUITMENT RELATIONSHIP USING THE COMPOSITE ABUNDANCE INDEX AND THE MIDWATER TRAWL INDEX
The midwater trawl regression is significant ($p<0.01$, r^2=0.39).
Source: Kimmerer 1992.

The composite index, calculated as the first principal component of the three indices, explained 79 percent of the variance in the three indices ($p<0.01$, r^2=0.79, N=20) and is, therefore, regarded as a surrogate for all three in representing the general trend in smelt abundance. His analysis of midwater trawl data for recruitment years 1968 to 1991 showed a large and significant portion ($p<0.01$, r^2=0.392, N=20) of the variance in recruitment could be explained by adult stock size.

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Our results using the same database support Kimmerer's findings based on midwater trawl indices ($p<0.01$, $r^2=0.39$, N=20). Recently, however, these indices have been revised for some years. Inclusion of the 1992 recruitment data and revised indices resulted in a decline in the amount of variability in recruitment attributed to spawning stock size from 39 percent to 27 percent ($p<0.05$, $r^2=0.266$, N=21). A similar analysis by Sweetnam and Stevens (1993) using nontransformed data found spawning stock accounted for 24 percent of the variability in recruitment (no level of significance stated, $r^2=0.24$, N=21).

Because stock and recruitment are not typically normally distributed, the significance of the SR relationship was also examined nonparametrically using Spearman's rank correlation test. A significant positive association ($p<0.01$, Spearman's correlation coefficient = 0.622, N=21) was found between stock and recruitment for 1967 to 1992.

The Beverton-Holt stock-recruitment model implies that, beyond some level of adult stock, there will effectively be no further increases in recruitment (Hankin 1980). That is, beyond some optimum stock abundance level, recruitment becomes essentially independent of stock abundance. The model results further suggest that environmental factors between egg and recruitment most strongly influence abundance of recruits of the next year class. However, even when recruitment is assumed to vary greatly in relation to environmental variability, long-term sustainability of yield from a fishery appears to depend mainly upon the degree to which the stock may be reduced before recruitment is significantly impaired (Koslow 1992).

Application of this stock-recruitment theory to the delta smelt population suggests that below some level of spawning stock the ability of the population to continue is probably hindered and recruitment significantly impaired. This supports the basic conclusions of Stevens *et al* (1990) and Moyle *et al* (1992). Fish populations are typically regulated mainly by highly variable factors (*ie*, predation, environmental variability, food availability) unrelated to stock size, except at extremes in population size (Strong 1986 cited by Koslow 1992). Sweetnam and Stevens (1993) also suggest that environmental factors cause much of the annual variation in delta smelt abundance, but that losses of spawning stock may have played an important role in the population's recent decline and may inhibit recovery.

The spawning stock may not need to be large for the species to perpetuate itself, as postulated by Moyle and Herbold (1989). For example, delta smelt recruitment was the highest on record in 1970, yet the spawning stock was fairly low. Conversely, a large spawning stock does not necessarily result in large recruitment, as indicated by 1981 recruitment. Based on stock-recruitment data from 1967 to 1992, it does appear that smaller delta smelt stocks will, in general, produce low to moderately low recruitment.

The decline of delta smelt was apparently due to poor recruitment from 1983 to 1989, the period of poorest recruitment on record. Exactly what caused this poor recruitment is still unclear. Recruitment was good in 1970-1973 and 1980 and was moderately low in 1967-1969, 1975-1978, and 1990-1991. It is not known what conditions caused the high recruitment in 1970 and 1980 and then the low recruitment in 1981 despite a good spawning stock. Since the tow-net index in 1981 was moderately good, something must have happened over the summer between the period when the tow-net index was set and when the midwater trawl index was calculated.

CVP/SWP OPERATION SIMULATIONS

DWR Planning Simulation Model, DWRSIM, was used to simulate monthly operation of existing Central Valley Project and State Water Project facilities under the water demands and operational constraints expected during the next few years. The model accounts for total availability, storage, release, and use of water in the Sacramento and San Joaquin river systems, the Delta, and the aqueduct systems south of the Delta. Input to the model is historical hydrology adjusted for future upstream depletions and water demands. The present model uses a 1995 level of hydrology and upstream depletions from Bulletin 160-93 land use projections (DWR 1993c). Model output includes monthly data on reservoir storage and releases, monthly inflows to the Delta, and monthly exports and outflows from the Delta.

Modeling Assumptions

Modeling assumptions were based on the February 1993, National Marine Fisheries Service biological opinion for operation of the Central Valley Project and State Water Project for winter-run Chinook salmon and Decision 1485. The simulation included existing facilities for a 71-year period, 1922 to 1992. Combined, rather than individual, SWP and CVP exports were modeled because of uncertainties about future Tracy and Banks pumping plant operations under the Coordinated Operation Agreement. CVP and SWP annual demands were assumed to total about 7 million acre-feet.

Not all of the 13 criteria required by the biological opinion in the "Reasonable and Prudent Alternative" (see Chapter 4) could be modeled in DWRSIM. Those items that were included are summarized below (using the NMFS numbering sequence).

2. End-of-water-year (September 30) carry-over storage in Shasta reservoir is maintained at 1.9 MAF in normal years. In some critical years, however, it was not possible to meet this criterion.
3. A minimum flow of 3,250 cfs from Keswick Dam to the Sacramento River is maintained from October 1 through March 31 of all water year types.
7. The Delta Cross Channel gates are maintained in the closed position from February 1 through April 30 of all water year types.
9. QWEST flow is maintained at greater than or equal to 0 cfs from February 1 through April 30 of all water year types.
10. QWEST flow is maintained at greater than –2,000 cfs from November 1 through January 31 of all water year types. This standard was not dropped whenever Mallard Slough water quality is better than or equal to 3.0 µS/cm specific conductance.

Additional assumptions for the single modeling run, NMFS-186, are listed in Appendix A.

The most significant criterion that could not be modeled was the "take" limit of winter-run at the SWP and CVP export pumps in the Delta, which required significant reductions in exports in 1993 even when all water quality and flow criteria were met.

Model Limitations

The modeling approach for the present study is not the usual use of DWRSIM. The model is most effective for comparisons of relative impacts of different scenarios, but only one set of operation criteria could be identified for the present assessment. A "no project" base could not be identified for comparison. Modeling statewide hydrology without project operation is not realistic, because project reservoirs and the Delta Cross Channel have critical flood control functions.

Model simulations do not include all operating constraints, so predicted flows and reservoir elevations may not fully represent "real world" conditions. For example, water temperature criteria in the Sacramento River and winter-run Chinook salmon "take" limits at Banks and Tracy pumping plants could not be modeled but could have a major effect on operations. The model also does not include any water exchanges and transfers to alleviate critical shortages or real-time operational management to optimize water availability and meet Delta standards. Furthermore, additional North Bay Aqueduct diversions to meet water quality standards in the western Suisun Marsh were not modeled.

The operation studies are based on meeting CVP and SWP contractors' <u>annual</u> requests. In conjunction with meeting these requests, the projects are operated to maximize storage south of the Delta to meet the following year's water demands. SWP demands of 3.6 million acre-feet used in the operation studies are near the current demand level of 3.854 million acre-feet. However, the operation studies do not address situations when all the contractors' demands are met, storage south of the Delta is full, there is still water available in the Delta, and "unused" pumping capacity is available at Tracy and Banks pumping plants.

The "unused" pumping capacity is the difference between direct delivery requirements of the contractors and the maximum pumping capability at the plant (while meeting all Delta and permit requirements). While this situation is not expected to occur frequently under the current Endangered Species Act restrictions, it will happen, and the pumping capacity should be used. This coming winter is an excellent example of this situation. The SWP share of San Luis Reservoir is expected to fill by October 31, 1993. Pumping capacity at Banks Pumping Plant from November 1993 through April 1994 will be greater than required to meet contractors' direct delivery requirements in that period. This available pumping capacity could be used to move additional water south of the Delta to wherever storage space can be found. This extra water would then be used in the future to offset deficiencies caused by restricted Delta pumping.

Chapter 7
ANALYSIS OF CVP AND SWP IMPACTS ON DELTA SMELT

Results of the DWRSIM modeling run to assess project impacts are summarized in Figures 67 through 74 for different water year types. These figures show the range of potential Delta hydrodynamic conditions and pumping levels that might occur during the mid-1990s with operation of existing Central Valley Project and State Water Project facilities. The expected impacts on delta smelt, based on current modeling capabilities and assumptions, are described below. Many of these assumptions linking water management operations and delta smelt behavior and impacts are being assessed. Many such associations and correlations are inconclusive and may be subject to further evaluation. Thus, modeling results may be revised to reflect CVP and SWP impacts.

Tracy Pumping Plant and Banks Pumping Plant

Simulated future exports for Tracy Pumping Plant and Banks Pumping Plant (combined pumping), North Bay Aqueduct, and Contra Costa Canal are presented in Figures 67 to 69. Each of these facilities results in entrainment and associated losses of delta smelt that would not occur if the project were not present.

The magnitude and timing of losses at the State Water Project and Central Valley Project appear to result from complex interactions of several factors, including flow, delta smelt distribution, and cohort abundance. The most likely mechanism for flow and distribution effects is that in low outflow years the delta smelt population shifts to upstream areas, where entrainment risks are greater. The impact of losses following entrainment is expected to be greater when year-class strength is weak. Year-class strength appears to depend at least partly on the number of adult spawners the previous year. Rationale for this hypothesis is described below.

A shift in population distribution has been established by Stevens *et al* (1990). The cause of the distribution shift appears to be increased salinity in Suisun Bay and the western Delta during drier years, discussed in Chapter 5 under "Water Quality".

Actual levels of entrainment and associated losses at the Central Valley Project and State Water Project Delta facilities are not known because information is lacking about screening efficiencies and predation rates. Without this information, salvage at the export facilities provides only an index of the relative timing and magnitude of entrainment and losses.

The major evidence for increased losses during drought years is the significant relationship between March-to-May salvage of juvenile delta smelt at Skinner Fish Facility and total Delta outflow during periods of peak abundance. Salvage levels at Tracy Fish Facility appear to be higher in many dry years, but further analyses are needed to accurately separate juveniles from adults in the salvage data. Diversion, entrainment, and losses are discussed in Chapter 5.

The higher risk of entrainment and, presumably, associated losses in the interior Delta is consistent with DWR Particle Tracking Model studies (Chapter 5), which indicate the export pumps have a "zone of influence" in the interior Delta from which a large percentage of modeled particles were entrained. If the distribution of delta smelt is shifted into this area, losses from entrainment are likely to increase.

Although flows in the western Delta were also shown to be significantly correlated with SWP salvage, particle tracking studies suggest reverse flows are not a good indicator of entrainment. Model studies showed particles in the interior of the Delta were carried to the export pumps despite high positive QWEST values. QWEST and actual western Delta flow are not equivalent, but often show similar trends. The association between western Delta flow and salvage may, therefore, be due to the correlation between western Delta flow and Delta outflow or other factors, rather than to a direct cause-and-effect relationship. The relationship between Delta inflow and SWP salvage may be due to a similar reason. As evidence that Delta outflow is a better indicator of entrainment and associated losses, this variable had a higher r^2 value with salvage than either western Delta flow or Delta inflow. Although export levels could change the area affected by pumping, exports were not found to be correlated to salvage levels, even when drought years are isolated. Hence, although future exports will continue to be higher in wetter years when outflow is high (Figure 67), statistical evidence suggests impacts will be lower in wetter years than in drier years.

While outflow appears to be a major hydrologic variable associated with SWP entrainment and loss, impacts to the smelt population also depend on year-class strength. If year-class is weak, the relative impacts of entrainment-related losses to

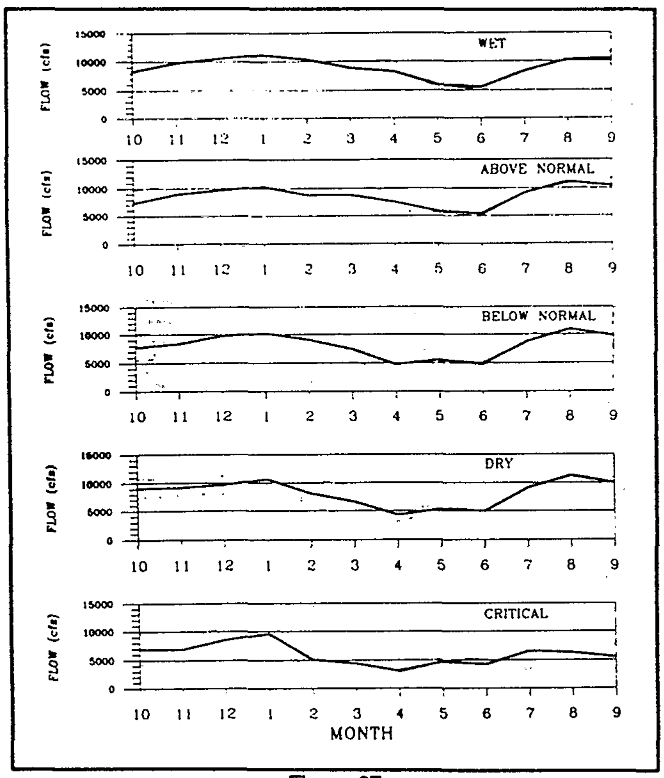

Figure 67
COMBINED BANKS AND TRACY PUMPING PLANT EXPORTS
FOR FIVE WATER-YEAR TYPES,
BASED ON A 71-YEAR SIMULATION
Average (solid line) and Standard Deviation (broken line)

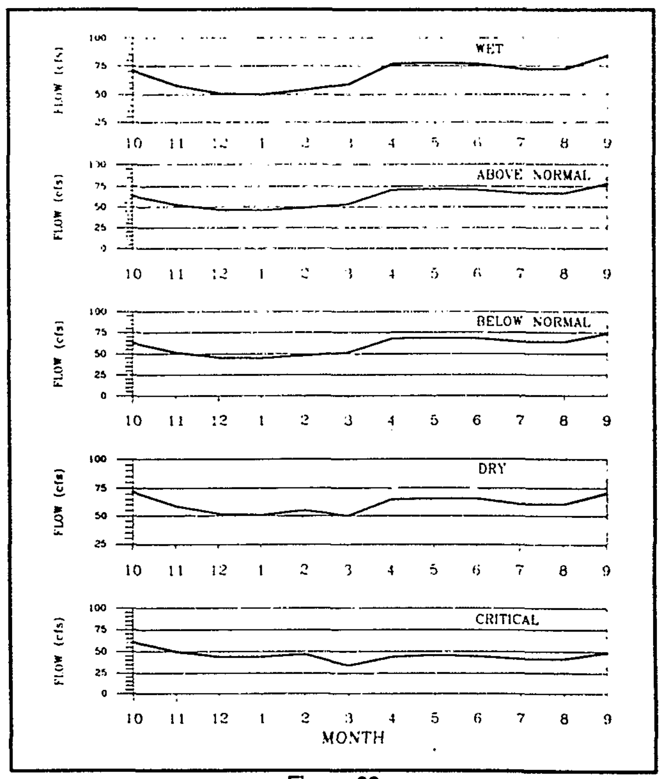

Figure 68
NORTH BAY AQUEDUCT DIVERSIONS
FOR FIVE WATER-YEAR TYPES,
BASED ON A 71-YEAR SIMULATION
Average (solid line) and Standard Deviation (broken line)

the delta smelt population are expected to be worse. SWP and CVP entrainment indices developed to incorporate cohort abundance generally follow the same trend as the salvage/outflow relationship. Impacts for 1979 to 1993 were usually lower in wet years and high in most drought years. There are, however, some anomalies to this trend (*eg*, 1984), indicating that additional factors must be considered.

Based on these observations, it is not surprising that no simple relationship has been found between delta smelt abundance indices and exports. It is possible that direct losses have little effect on abundance indices except in drought years when cohort strength is weak. As a result, population level impacts for the simulated exports (Figure 67) and outflow (Figure 73) cannot be specified, because we do not know year-class strength in advance. Based on the significant stock-recruitment relationship for delta smelt, year-class strength depends at least partly on the number of spawners the previous year. In addition, the distribution of exports between the State Water Project and Central Valley Project is not known because of uncertainties about the Coordinated Operation Agreement, so potential differential losses at the two facilities cannot be identified. Nonetheless, impacts will likely be lower than in the 1980s, because winter-run salmon take limits will result in reduced exports during winter and spring, when entrainment appears to be highest. Incidental loss from entrainment of delta smelt will be further reduced in drier years, as exports are limited to meet QWEST requirements.

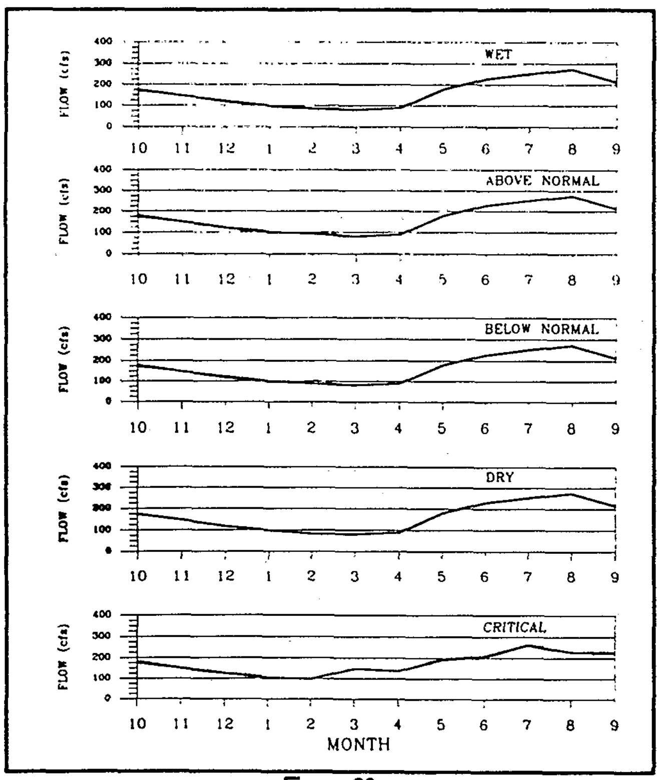

Figure 69
CONTRA COSTA CANAL DIVERSIONS
FOR FIVE WATER-YEAR TYPES,
BASED ON A 71-YEAR SIMULATION
Average (solid line) and Standard Deviation (broken line)

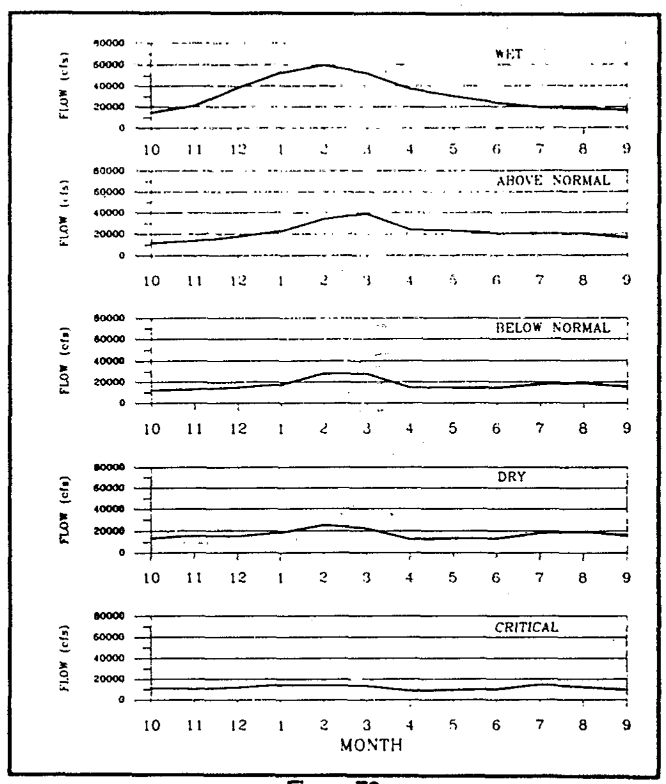

Figure 70
SACRAMENTO RIVER INFLOW TO THE DELTA
FOR FIVE WATER-YEAR TYPES,
BASED ON A 71-YEAR SIMULATION
Average (solid line) and Standard Deviation (broken line)

North Bay Aqueduct

The presence of delta smelt larvae in Barker and Lindsey sloughs near the North Bay Aqueduct intake since 1986 suggests a small number of smelt are entrained at this facility, at least in dry years. At present, data are insufficient for predicting loss levels, but future impacts could be different due to increased diversions to help meet Decision 1485 salinity standards in western Suisun Marsh. If tests in 1994 show efforts to improve salinities in western Suisun Marsh are successful, additional diversions from January through March could be up to 50 cubic feet per second and from April through May could be up to 30 cfs greater than shown in the simulations of critical and dry years (Figure 68). Based on historical hydrology, this would occur in 15 percent of years but would depend on the seasonal pattern of rainfall and flow. However, increased losses at the North Bay Aqueduct could be partially offset by improved water quality in northwestern Suisun Marsh, thereby providing additional low-salinity habitat for smelt in drought years.

Contra Costa Canal

Entrainment data for Contra Costa Canal are limited, making it difficult to estimate loss rates. A transport modeling simulation for the proposed Los Vaqueros Project based on specific hydrology, smelt abundance, and distribution suggests losses could be substantial (Jones and Stokes 1992). The degree to which model results represent the variability in smelt abundance and distribution under actual conditions is not known.

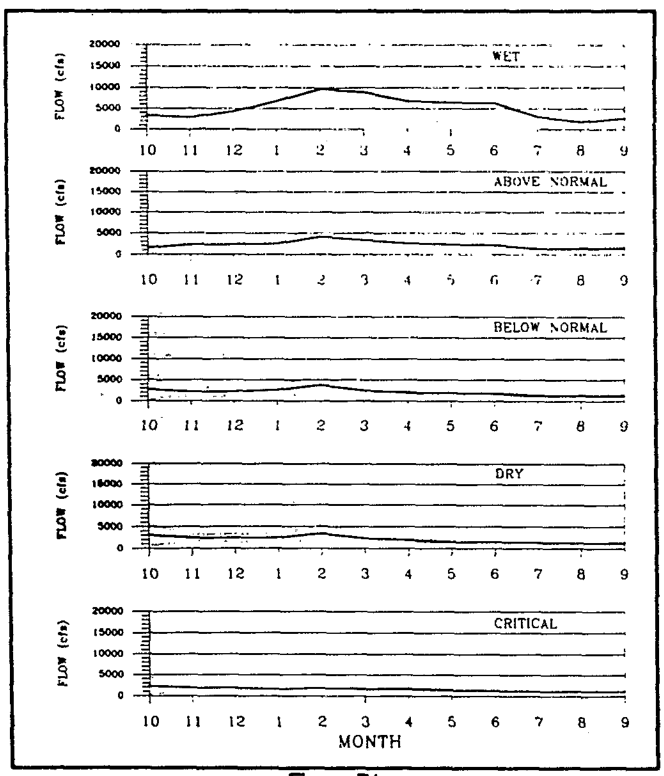

Figure 71
SAN JOAQUIN RIVER FLOW NEAR VERNALIS
FOR FIVE WATER-YEAR TYPES,
BASED ON A 71-YEAR SIMULATION
Average (solid line) and Standard Deviation (broken line)

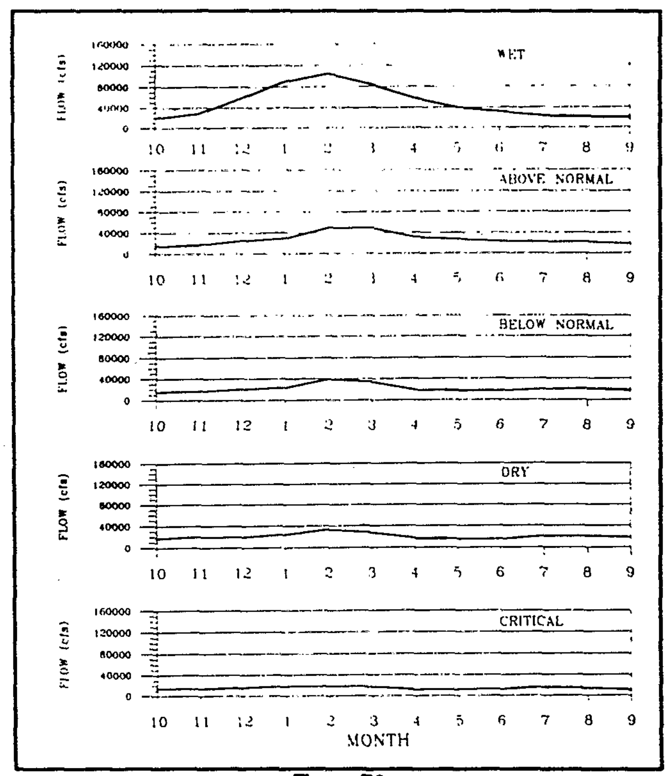

Figure 72
TOTAL DELTA INFLOW, INCLUDING PRECIPITATION,
FOR FIVE WATER-YEAR TYPES,
BASED ON A 71-YEAR SIMULATION
Average (solid line) and Standard Deviation (broken line)

Based on salvage results from Skinner and Tracy fish facilities, delta smelt may also be more vulnerable during drought years, when their distribution shifts closer to the diversion. Impacts at the population level could also be greatest when drought coincides with low year-class strength.

Suisun Marsh Salinity Control Facilities

Monitoring indicates the Suisun Marsh Salinity Control Gates have had minimal adverse impacts on delta smelt, and there is no evidence that continued operation of the gates would create additional impacts. The impacts of the Western Suisun Marsh Salinity Control Project would be the same as those described for the North Bay Aqueduct.

The Roaring River Diversion has been found to entrain delta smelt, although addition of a fish screen appears to have significantly reduced those impacts. Entrainment is expected to continue at low levels when delta smelt are present in Suisun Marsh. However, delta smelt have become increasingly rare in the marsh since 1981, so entrainment may be infrequent until the population recovers.

Delta Inflow and Outflow

Average Sacramento River flow, average San Joaquin River flow, total Delta inflow, and total Delta outflow from the 71-year simulation are presented in Figures 71 to 73 for each water year type. Impacts of project-related changes to flow on direct loss are described earlier in this chapter. Altered flow patterns in the estu-

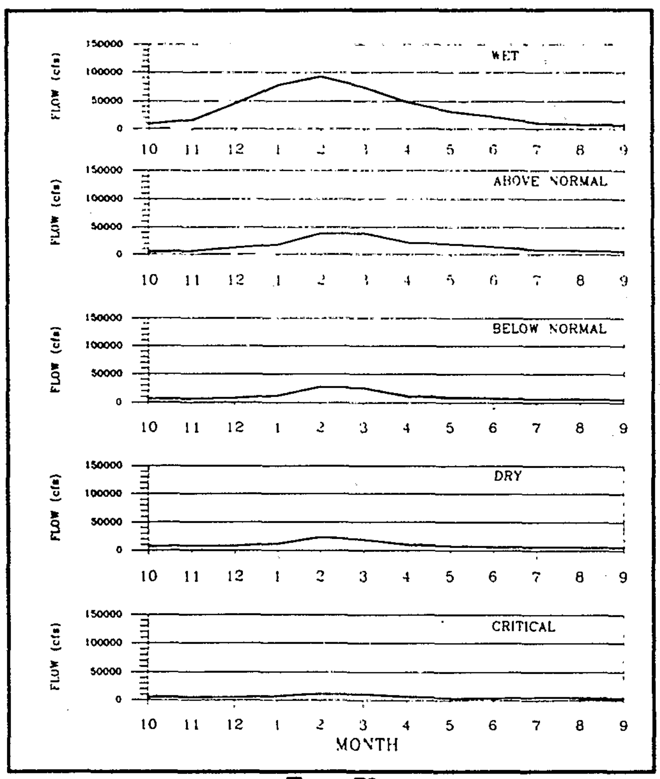

Figure 73
TOTAL DELTA OUTFLOW
FOR FIVE WATER-YEAR TYPES,
BASED ON A 71-YEAR SIMULATION
Average (solid line) and Standard Deviation (broken line)

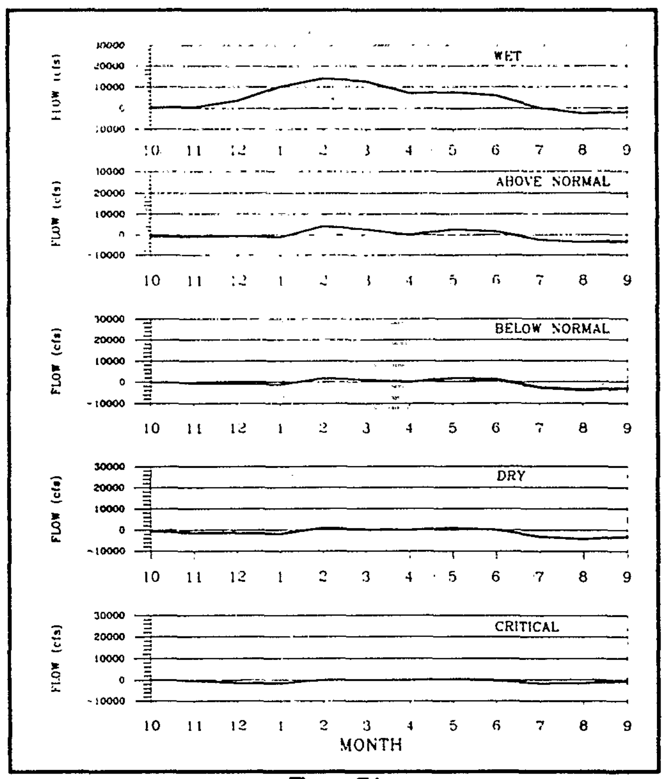

Figure 74
QWEST FLOWS FOR
FIVE WATER-YEAR TYPES,
BASED ON A 71-YEAR SIMULATION
Average (solid line) and Standard Deviation (broken line)

ary could have other impacts to delta smelt, including changes in entrainment rates at agricultural or industrial diversions.

Upstream reservoir storage and project exports reduce outflow in winter and spring, contributing to an incremental upstream shift in delta smelt distribution. However, releases from CVP and SWP reservoirs also maintain summer and fall outflow higher than it would be without the projects. Particle tracking studies suggest entrainment by agricultural diversions may be high if delta smelt are forced to move into the interior Delta. Changes in outflow could also move delta smelt populations closer to or farther from the influences of PG&E diversions near the confluence of the Sacramento and San Joaquin rivers. However, the lack of a significant relationship between outflow and abundance indices (Moyle *et al* 1992; Stevens *et al* 1990) implies that outflow is not a reliable direct measure of population level impacts to delta smelt. Nonetheless, changes in Delta outflow due to project operation could alter delta smelt losses at agricultural diversions. The net effect of outflow changes on losses from entrainment and impingement at PG&E facilities would be either beneficial or detrimental, depending on the water year.

Changes in delta outflow resulting from project operation may also affect the position of the entrapment zone. Although a weak statistical relationship was found between the fall midwater trawl index and entrapment zone position, the association is apparently due to autocorrelation from stock-recruitment effects. Therefore, there is no clear evidence that project-related changes in the entrapment zone will affect delta smelt abundance.

Reverse Flow

Results from the model DWRSIM, summarized in Figure 74, indicate QWEST is generally positive in wet years, but net reverse flows are common in August and September. In other water year types, net reverse flows are frequently strongest from July through September and range from –2000 to +2000 cfs the rest of the year. The export facilities contribute to net negative reverse flows that would not occur without SWP and CVP pumping in the Delta.

Although there has been some concern that net reverse flow may be detrimental to delta smelt (Moyle *et al* 1992), no association has been found between QWEST and abundance indices. Moreover, modeling studies show that particles, and presumably young fish, in areas west of Antioch are only slightly affected by net reverse flows (QWEST = –2000 cfs). Model results also suggest QWEST is a poor indicator of entrainment of particles at SWP, CVP, and agricultural diversions because entrainment occurs in the interior delta even at high positive QWEST values. While these results should be interpreted with caution because smelt do not behave like neutrally-buoyant particles, they at least indicate the major processes. Therefore, the QWEST levels shown in Figure 74 are not expected to create additional impacts to those identified for Delta outflow.

Delta Cross Channel Gates

Closing the Delta Cross Channel gates from February 1 through April 30 could create a barrier to some adult delta smelt migrating upstream to spawn. It is not known whether the Delta Cross Channel, with the radial gates closed, would provide acceptable spawning habitat similar to a dead-end slough (Radtke 1966) or whether operation would interfere with spawning success by delaying migration.

Operation of the Delta Cross Channel changes flow patterns in the Delta and may result in increased or decreased vulnerability of larval delta smelt to entrainment by CVP, SWP, agricultural, and industrial diversions. Modeling studies using tracers suggest closing the Delta Cross Channel could reduce entrainment and subsequent loss of larval fish spawned in the Sacramento River but adversely impact fish spawned in the lower San Joaquin River system. Given these conflicting results and uncertainties about the degree to which tracers simulate larvae, the overall impact of Delta Cross Channel operation is not known. Impacts are likely related to the annual distribution of spawning between the two river systems.

South Delta Temporary Barriers

As discussed in Chapter 5, the South Delta Temporary Barriers Program has had little or no effect on CVP or SWP losses, egg and larval distribution, or predation near the barriers (DWR 1993b). Given the extremely small number of Delta smelt in the project area, future temporary barrier operations are not expected have significant impacts. Nonetheless, transport modeling studies suggest losses could occur under certain conditions of barrier operation (DWR 1993b). These results should be interpreted with caution, because the tracer mass may not be a realistic surrogate for Delta smelt eggs and larvae.

Chapter 8

CUMULATIVE EFFECTS

Cumulative effects are those impacts resulting from future State and other non-Federal actions that are not subject to consultation requirements established in Section 10 of the Endangered Species Act. These actions may affect listed species occurring or reasonably certain to occur in the action area. Future Federal actions are subject to the consultation requirements established in Section 7 of the Endangered Species Act and, therefore, are not considered cumulative to the proposed action. The cumulative effects mentioned below have been discussed in preceding chapters and are summarized here.

Cumulative effects on delta smelt include any diversion of water that may entrain adults or larvae or that decrease outflows incrementally and cause a shift in the preferred habitat of delta smelt to less than optimal areas. Another component of decreased outflows is salt water intrusion, which may allow competing organisms, such as the Asian clam, to extend their ranges and increase their populations. These organisms compete with delta smelt for food. Numerous water diversions for agriculture, duck clubs, power plants, and municipal/industrial uses upstream of the Delta, in the Delta, and in Suisun Bay contribute to these cumulative effects.

Other cumulative effects are predation, limited food, disease, and parasites. Cumulative effects can also include chemical contamination from point and non-point discharges that may adversely affect survival rates and reproductive success. Pesticides, herbicides, and selenium have all been suggested as potential sources of delta smelt mortality.

Although these cumulative effects operate together with the effects of the proposed action to influence the status of delta smelt, the relative importance of these factors to delta smelt abundance is not clear. Any program or proposal to reduce the threat of jeopardy to delta smelt or to help recover delta smelt populations may need to address all these factors to assure effectiveness.

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Appendix A
DWRSIM ASSUMPTIONS IN ADDITION TO CHINOOK SALMON BIOLOGICAL OPINION OPERATIONS

- Revised 1995 level hydrology and upstream depletions, based on DWR Bulletin 160-93 land use projections (71 years, 1992-1992).

- Minimum Delta outflow requirements are maintained to satisfy Decision 1485, assuming interim Suisun Marsh criteria.

- Existing CVP and SWP facilities are assumed.

- Carriage water requirements based on allowable export/salinity repulsion curves for Rock Slough, designed to maintain an average monthly water quality of 130 ppm chlorides during winter and spring and 225 ppm chlorides during summer and fall, with buffer for actual 150/250 standard.

- SWP Banks Pumping Plant average monthly capacity with four new pumps is 6,680 cfs (or 7,300 cfs in some winter months) in accordance with the U.S. Army Corps of Engineers permit criteria. Pumping is limited to 3,000 cfs in May and June and 4,600 cfs in July to comply with Decision 1485 criteria for striped bass survival. In addition, SWP pumping is limited to 2,000 cfs in any May or June in which storage withdrawals from Lake Oroville are required (per the January 5, 1987, Interim Agreement between the Department of Water Resources and Department of Fish and Game).

- CVP Tracy Pumping Plant capacity is 4,600 cfs, but constraints along the Delta-Mendota Canal and at the re-lift pumps (to O'Neill Forebay) restrict export capacity to 4,200 cfs at those points. Pumping is also limited to 3,000 cfs in May and June in accordance with Decision 1485 criteria for striped bass survival.

- Wheeling of CVP water through SWP facilities to San Luis Reservoir is permitted as needed to offset CVP Tracy Pumping Plant compliance with Decision 1485 criteria in May and June. As specified in the Coordinated Operation Agreement, SWP pumping capacity will be made available so that CVP wheeling will be completed by the end of August each year.

  In addition, 128,000 acre-feet per year of CVP water is wheeled to meet Cross Valley Canal demands when unused capacity is available at SWP Banks Pumping Plant.

- CVP/SWP sharing of responsibility for coordinated operation of the two projects is maintained per the Coordinated Operation Agreement. Storage withdrawals for in-basin use are split 75 percent CVP and 25 percent SWP. Unstored flow for storage and export is split 55 percent CVP and 45 percent SWP.

- New Trinity River minimum fish flows below Lewiston Dam are maintained at 340,000 acre-feet per year for all years, based on the May 1991 letter of agreement between the U.S. Bureau of Reclamation and the U.S. Fish and Wildlife Service.

- Sacramento River minimum fishery flows below Keswick Dam are maintained per the agreement between the U.S. Bureau of Reclamation and the California Department of Fish and Game (as revised October 1981). These flows range from 2,300 to 3,900 cfs, depending on the time of year, per the Bureau of Reclamation's Shasta criteria.

- Sacramento River navigation control point flows are maintained at 5,000 cfs from April through October and 4,000 cfs from November through March of all normal CVP delivery years. During years when deficiencies are imposed on CVP water deliveries, flows are maintained at 4,000 cfs during all months of the year (assumed on a March-February basis) that deficiencies would be imposed.

- Feather River fishery flows are maintained per the August 26, 1983, agreement between the Department of Water Resources and Department of Fish and Game. In normal years, these minimum flows are 1,700 cfs from October through March and 1,000 cfs from April through September. Lower flows are allowed in dry and critical water years. In addition, the maximum flow restriction of 2,500 cfs for October and November is maintained per the agreement criteria.

- American River minimum fish and recreation flows are based on storage in Folsom Lake, per U.S. Bureau of Reclamation operation criteria. Minimum flows range between 250 and 2,000 cfs.

- Stanislaus River minimum fish flows below New Melones Reservoir range from 98,000 to 302,000 acre-feet per year , according to the June 1987 interim agreement between the Bureau of Reclamation and the Department of Fish and Game. The actual minimum fish flow for each year is determined based on the water supply available for that year.

- San Joaquin River water quality standards at Vernalis are maintained per State Water Resources Control Board Decision 1422 (500 ppm TDS on an average basis). Additional water is released from New Melones Reservoir when necessary to maintain these standards at Vernalis, up to a maximum of 70,000 acre-feet per year.

- Existing CVP Delta demands (in acre-feet per year) are assumed, as follows:

Contra Costa Canal	118,000
Delta-Mendota Canal and Exchange	1,484,000
CVP San Luis Unit	1,259,000
San Felipe Unit	196,000
Cross Valley Canal	128,000
Losses	179,000
Total CVP Delta Demand	3,364,000
Folsom-South Canal	65,000

- SWP contractor requests are set at 1992 level, as submitted by the contractors, and are met to the extent possible each year based on available supply. The amounts (in acre-feet per year) are:

North Bay Aqueduct	50,000
South Bay Aqueduct	189,000
SWP Dos Amigos	3,382,000
Recreation and Losses	64,000
Total SWP Demands	3,685,000